Electrostatic Precipitator (EP)

Our companies, and thousands more throughout the world, will be faced with a substantial environmental challenge over the next few years. Increased governmental regulation and enforcement of clean air laws will require your air pollution control equipment to consistently meet rigid performance standards. And with an electrostatic precipitator that is *always* a challenge.

1. TECHNOLOGY BASICS OF EP

1.1 How does an EP work?

Fig. 3 shows a schematic drawing of an electrostatic precipitator. An industrial precipitator has a number of passages through which the gases pass at a velocity of about 1 m/s. The passages are formed by two parallel rows of vertically mounted collecting plates and a number of discharge electrodes vertically suspended between the collecting plates.

Normally the spacing of the discharge and collecting electrodes varies between 125 and 200 mm and the voltage applied between them is 35 to 110 kV negative DC according to spacing, gas and dust conditions.

The high negative voltage applied to the electrically insulated discharge electrodes creates a strong electrical field between the discharge electrodes and the earthed collecting plates. The highest strength occurs near the discharge electrodes. As the voltage is raised, electrical breakdown of the gas close to the electrode surface takes place. This breakdown, called "corona", appears as a bluish glow extending into the gas a short distance beyond the surface of the discharge electrode.

The corona produces large numbers of gas ions, the positive ions being immediately attracted to the discharge electrodes while the negative ions migrate towards the collecting plates.

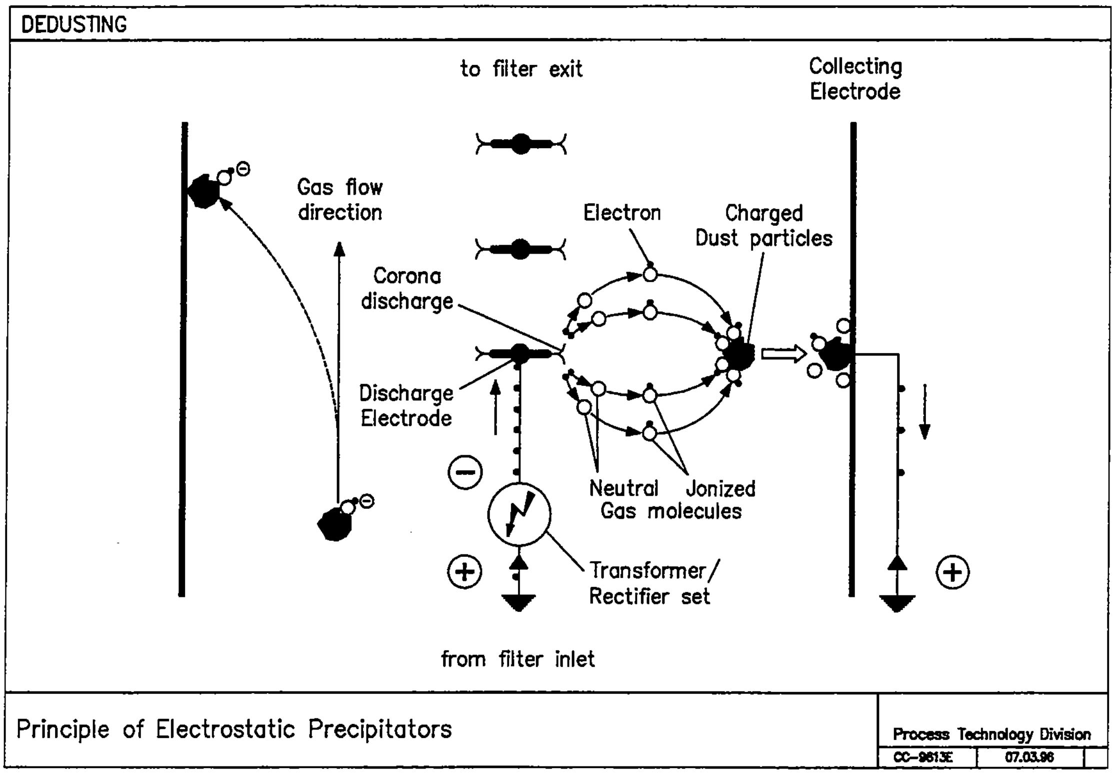
Some of the moving ions attach themselves to dust particles suspended in the gas between the electrodes. Dust particles are charged either by bombardment by the ions moving under the influence of the electrical field, or by ion diffusion, both types of charging taking place simultaneously. The particle size determines which type of charging is predominant, ion diffusion being the prevailing mechanism for particle sizes below 1 micron.

Through the influence of the electrical field, the negatively charged particles migrate towards the collecting plate to which they adhere while being electrically discharged.

These particles build up a layer of dust on the plate surface which is dislodged by rapping.

The dislodged particles fall by gravity towards the bottom of the precipitator, ending up in the bottom hopper from where the dust is extracted by either mechanical conveyor (drag chain or screw conveyor) or pneumatic type system.

Figure 3 How electrostatic precipitators work



1.2 How EP Efficiency is determined

There have been many attempts over the years to develop satisfactory equations based on fundamental theories in order to enable the efficiency of a precipitator to be forecast. They are contained in a large number of technical papers, which are conveniently summarized in H.E. White's book entitled "Industrial Electrostatic Precipitation". Generally the performance of EPs can be expressed by the following Deutsch formula:

$$\eta_{EP} = 1 - e^{\left(-\frac{\omega \cdot L}{v \cdot s}\right)} \qquad 2)$$

or

$$\eta_{EP} = 1 - e^{\left(-\omega \frac{A}{Q}\right)} \qquad 3)$$

where

η = Efficiency of the electrical precipitator
ω = Particle migration velocity (m/s)
A = Total projected collecting area (m^2)
Q = Gas flow (m^3/s)
L = Field length (m)
v = Gas velocity (m/s)
s = Distance between collecting and discharge electrodes (m)

From equation 3 it follows that the dedusting efficiency of a precipitator depends on:

I the migration velocity w (m/s)
II the total projected collecting area A (m^2)
III the gas flow Q (m^3/s)

1.3 How EP Clean Gas Dust Content is determined

If equations 1 and 3 are combined then one can describe the clean gas dust content r in function of

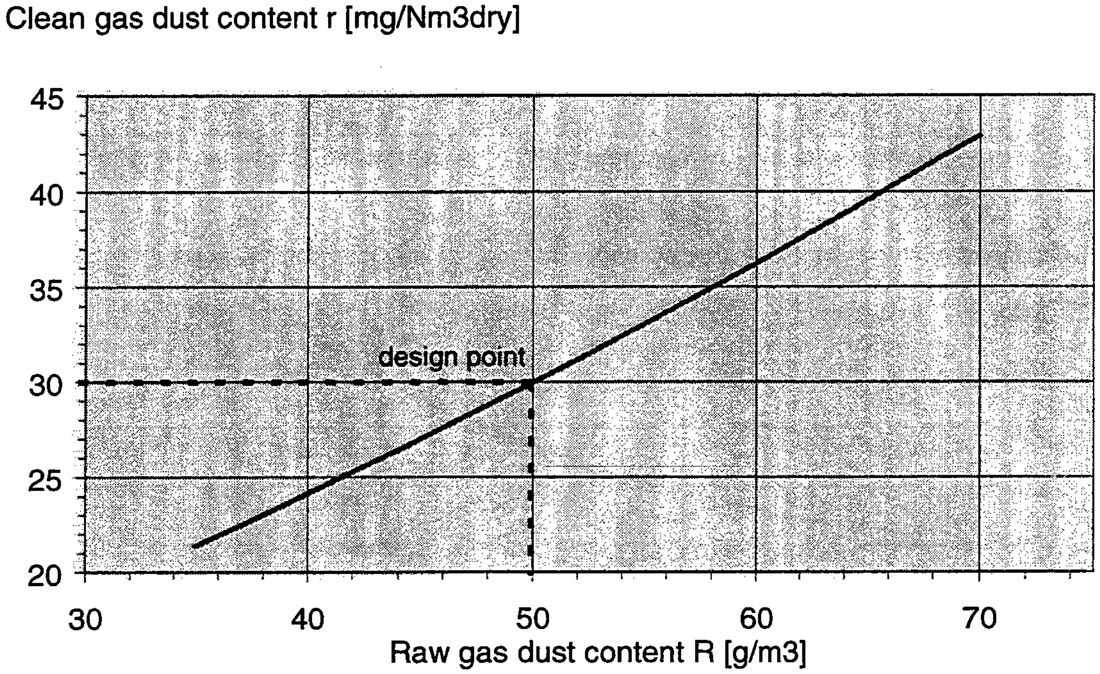
R	the raw gas dust content (g/m^3)
ω	the migration velocity (cm/s)
A	the total projected collecting area (m^2)
Q	the gas flow (m^3/h)

$$r = R \cdot e^{\left(-\frac{A}{Q} \cdot \varpi\right)} \qquad [mg/m3] \qquad 4)$$

1.3.1 Clean Gas Dust Content (r) in Function of the Raw Gas Dust Content (R)

With respect to equation 4, one would expect that the raw gas dust content (R) is directly proportional to the clean gas dust content (r). However, because the migration velocity is increasing with R, the effect of R on r is much weaker than expected.

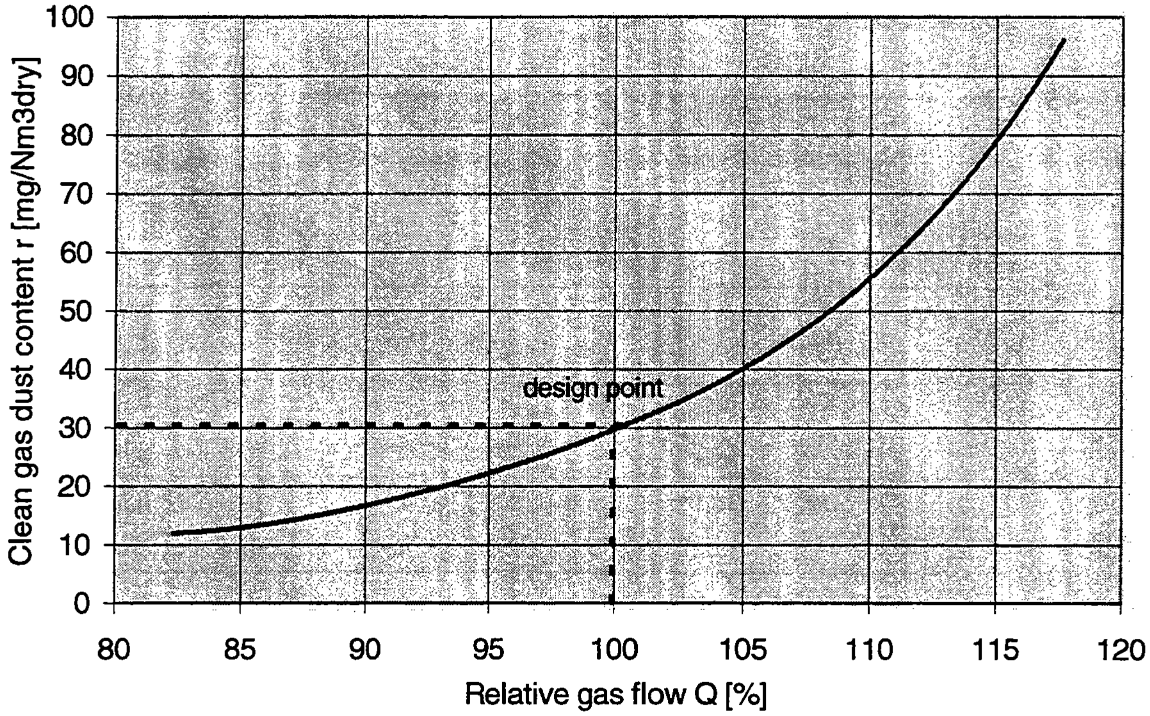
Figure 4 **Example of correlation between raw gas dust content R and clean gas dust content r**



1.3.2 Clean Gas Dust Content (r) in Function of the Gas Flow (Q)

The equation 4 shows that r is an exponential function of the inverse gas flow (Q). However, the migration velocity (ω) is also influenced by the gas flow. Therefore, the correlation of r and Q is not exactly according to the equation 4 with ω = constant.

Figure 5 **Example of a correlation between gas flow Q and clean gas dust content r for a modern kiln EP during compound operation**



At relative gas flows above 100%, r is increasing exponentially because of the exponential correlation of r and Q (equation 4) and the amplifiying effect of turbulence and dust re-entrainment from the collecting plates.

The latter is overlaid by other effects mainly based on physical and chemical changes of the particulates caused by the lower clean gas dust content (r).

At this point we already realize that the calculation of r is very complex because, unfortunately, migration velocity ω is not constant but a function of R, Q and other variables.

1.3.3 Clean Gas Dust Content (r) in Function of the Total Projected Collecting Area (A)

The total projected collecting area (A) is

$$A = l \cdot h \cdot G \cdot F \cdot 2 \qquad [m2] \qquad 5)$$

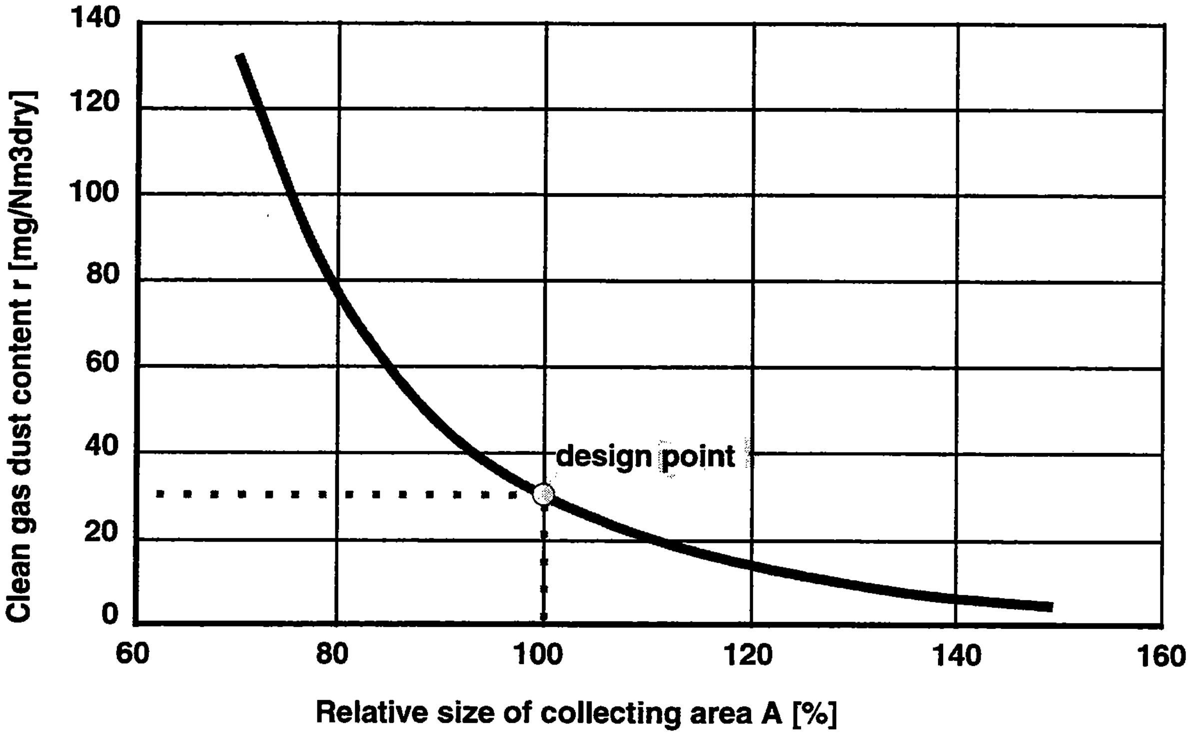
where

l = Length of field (m)
h = Height of field (m)
G = Number of gaps of one field (-)
F = Number of fields (-)

The factor of 2 is required because both sides of the collecting electrodes are active during the dust extraction process.

The correlation between A and r is about inverse to the correlation between Q and r (see equation 4). It is important to notice that the required collecting area is increasing exponentially with the reduction of the clean gas dust content.

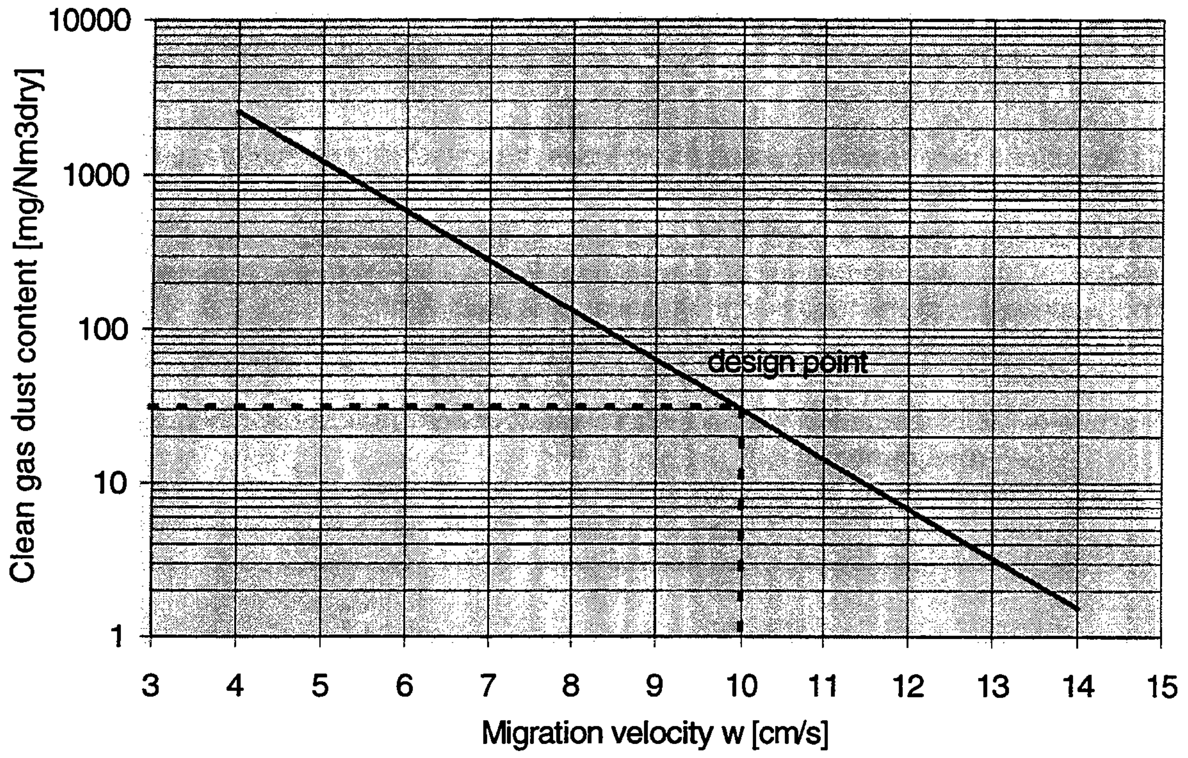
Figure 6 **Correlation between the projected collecting area A and the clean gas dust content r**



1.3.4 Clean Gas Dust Content (r) in Function of the Migration Velocity (ω)

Among the variables in equation 4 the migration velocity is the one with by far the most practical significance. Not because it has a stronger impact on r than the others (see equation 4) but because it represents the effect of all other variables besides Q, R and A on the EP efficiency.

Figure 7 Clean gas dust content r in function of the migration velocity ω



The migration velocity can, somewhat simplified, be understood as the average velocity of the dust particles in their migration from the discharge to the collecting electrode in the electrostatic field.

The migration velocity (ω) itself is a function of many other variables like

- Nature of dust
  - Electrical resistivity
  - Size
    Gas condition
  - Temperature
  - Volume
  - Humidity
  - Chemical composition
  - Dust load
  - False Air
- Energization of electrical fields
  - Voltage
  - Current
- EP design
  - Gas distribution
  - Electrode design
  - Electrode cleaning

and these are only the most important ones.
With this information we can rewrite equation 4 as follows:

$$r = R \cdot e^{\left(-\frac{A}{Q} \bullet \omega\,(\Omega, \varphi, T, Q, \tau, c, r, R, I, U, \sigma, \ldots)\right)} \qquad 6)$$

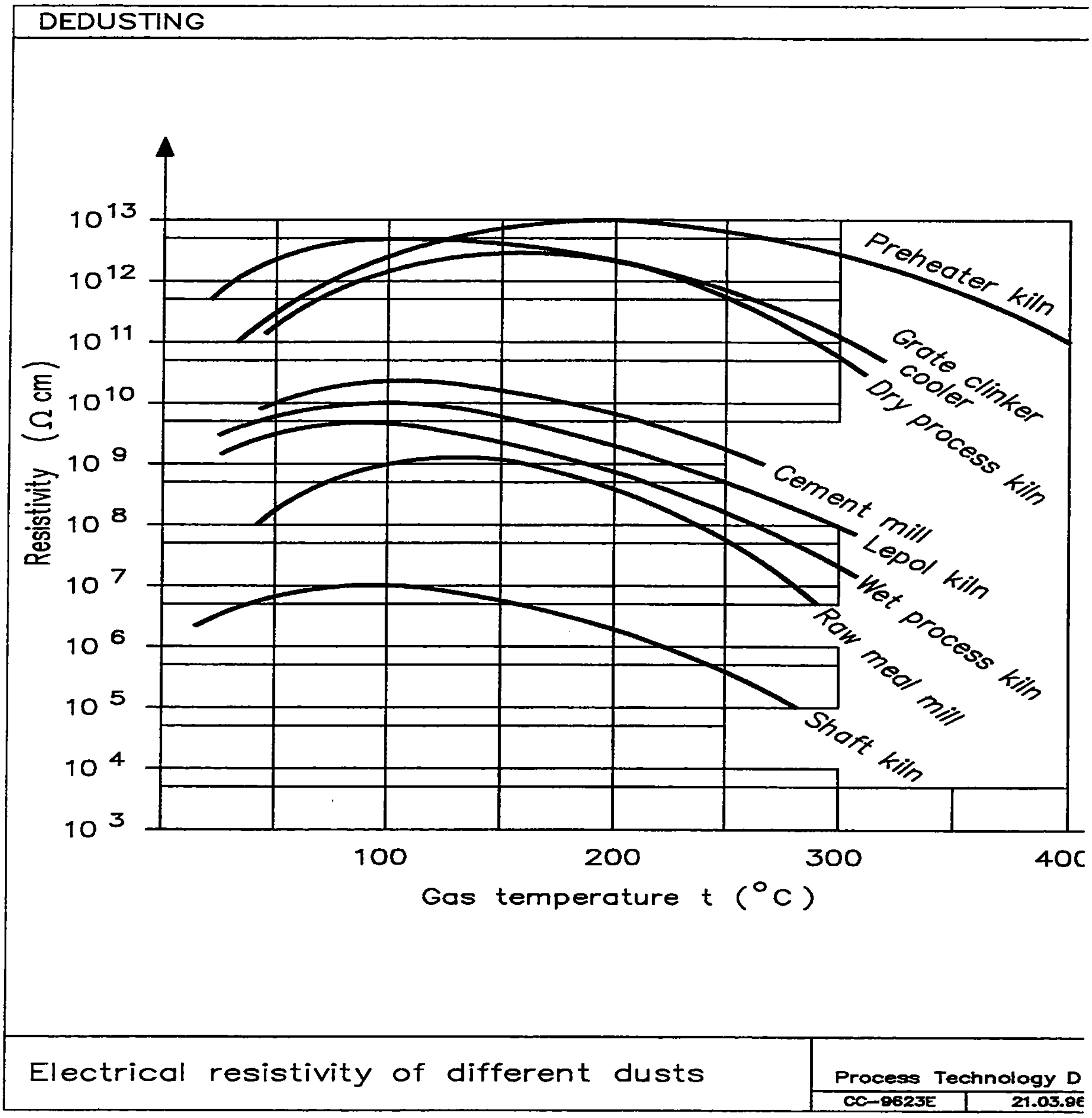
For most of the mentioned variables there exist empirical graphs describing the correlation between the variables and ω. Some of these graphs were published but others are the secrets of the suppliers.

Various attempts to calculate ω theoretically were not successful.

1.3.4.1 Electrical Resistivity of Dust

The electrical resistivity of the dust particles plays a very important part in the precipitation process and depends mainly on the type of the dust, the gas temperature and the gas humidity.

Figure 8 Dust resistivity in function of temperature and dust source



Three ranges of electrical resistivity can be distinguished:

- less than 10^4 Ω cm
- 10^4 to 10^{11} Ω cm
- more than 10^{11} Ω cm

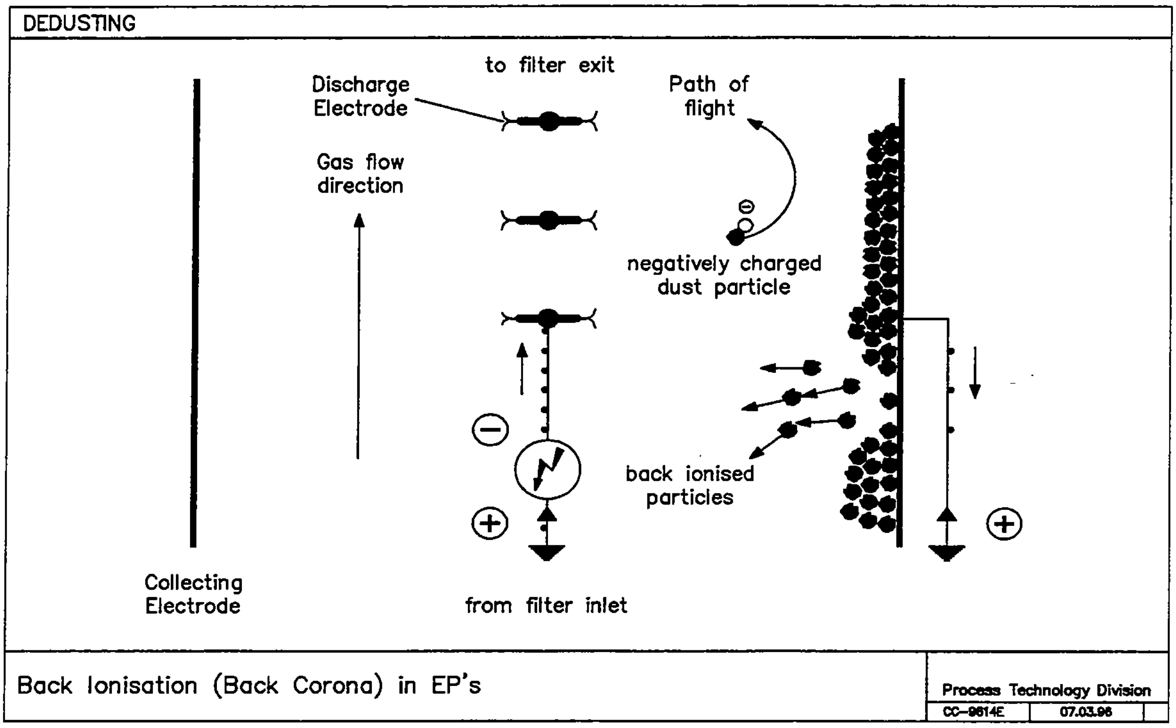
For particles having a resistivity of less than 10^4 Ω cm the electrical conductivity is so high that although they are charged in the normal manner and move normally under the influence of the electrical field, the attainable dedusting efficiency is poor. The reason thereof is that as soon as they reach the collecting electrodes, the electric charge leaks away so rapidly that the particles are repelled into the gas stream and most likely escape with the outlet gases.

Dust types belonging to the range comprised between 10^4 and 10^{11} Ω cm show a favorable discharge behavior. This means that neither particle repulsion nor back-ionisation occurs, i.e. the particles are nicely deposited on - and sufficiently attached to the collecting electrode.

Cement industry dusts usually belong to these "easily" separating dusts. Dusts stemming from long dry process kilns, suspension preheater kilns and grate clinker coolers, however, may occasionally develop dedusting problems.

Particles having resistivities of more than 10^{11} - 10^{12} Ω cm can form within a very short period of time an electrically insulating layer on the collecting electrodes leading to the so-called back-ionisation (back corona) effect. With "back-ionisation" already captured dust is forced back into the gas flow and a reasonable dedusting efficiency of the precipitator becomes impossible to obtain.

Figure 9 **Back ionization of dust particles at high electrical resistivities**

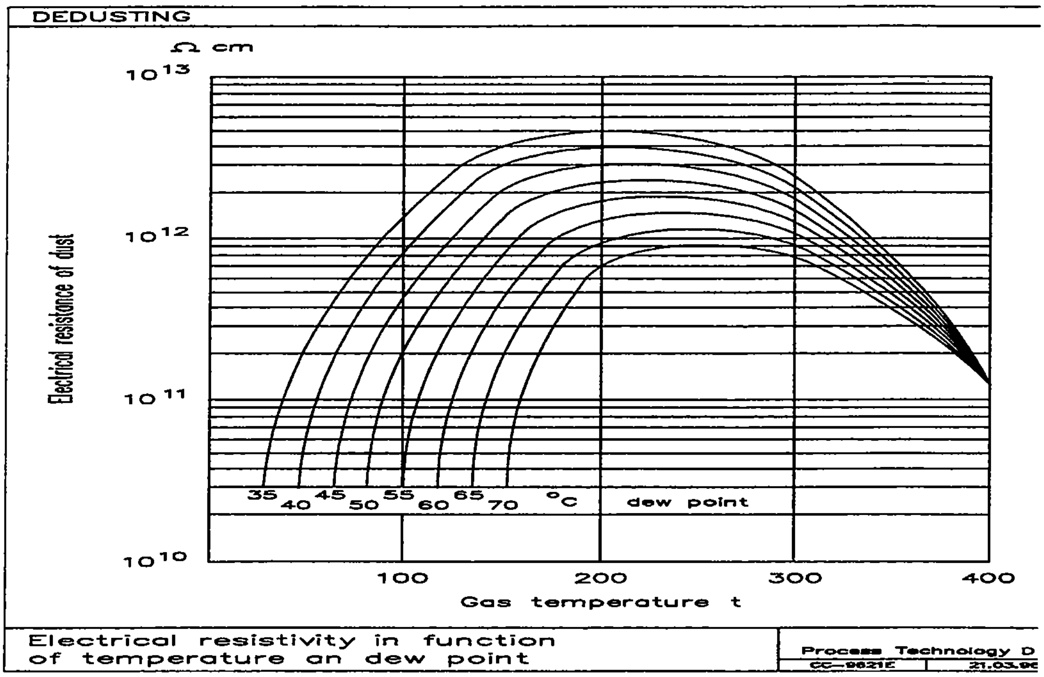


Dust resistivity at temperatures below 200°C is primarily determined by the amount of moisture present in the gas. Therefore, a wet kiln will have a much lower resistivity than a standard long, dry or a preheater kiln. In fact that was the reason why a water spray / conditioning tower was added to these kiln systems to tread the exhaust gas.

The variation of the resistivity as a function of the moisture content of the raw gas is due to an extremely thin conditioning layer on the particle surface which modifies the resistivity of the dust.

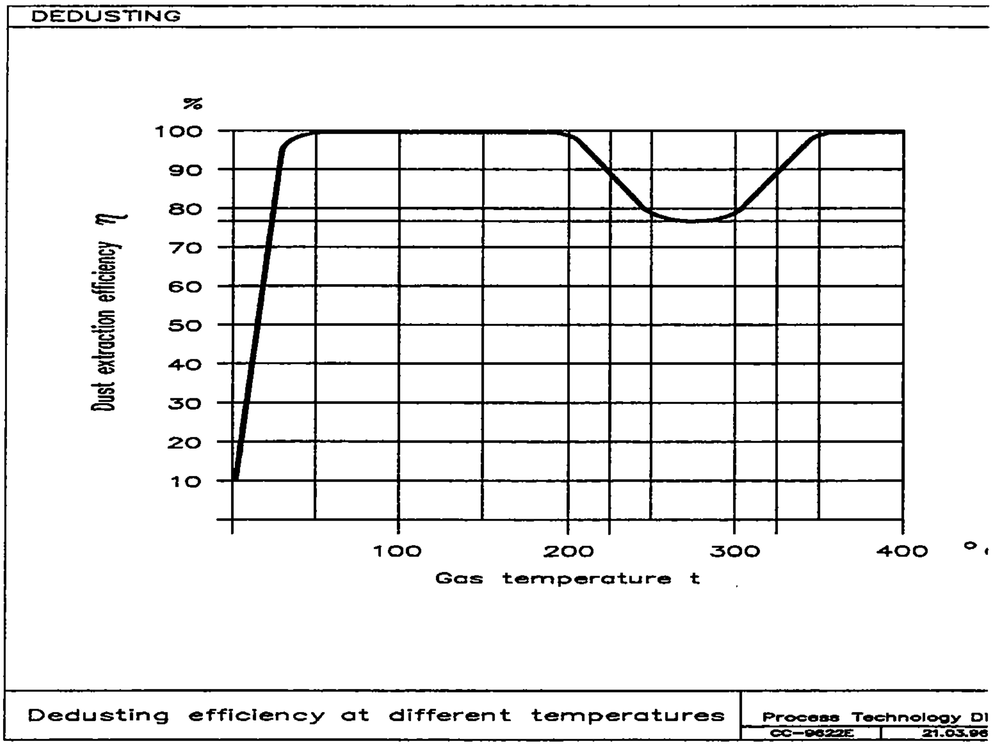
At higher temperatures (above 350°C) the particles become increasingly conductive and the gas composition ceases to have much effect as a such.

Figure 10 Dust resistivity in function of the temperature and the dew point



At middle-range temperatures of about 200 to 250°C the resistivity curve of some dust reaches a maximum.

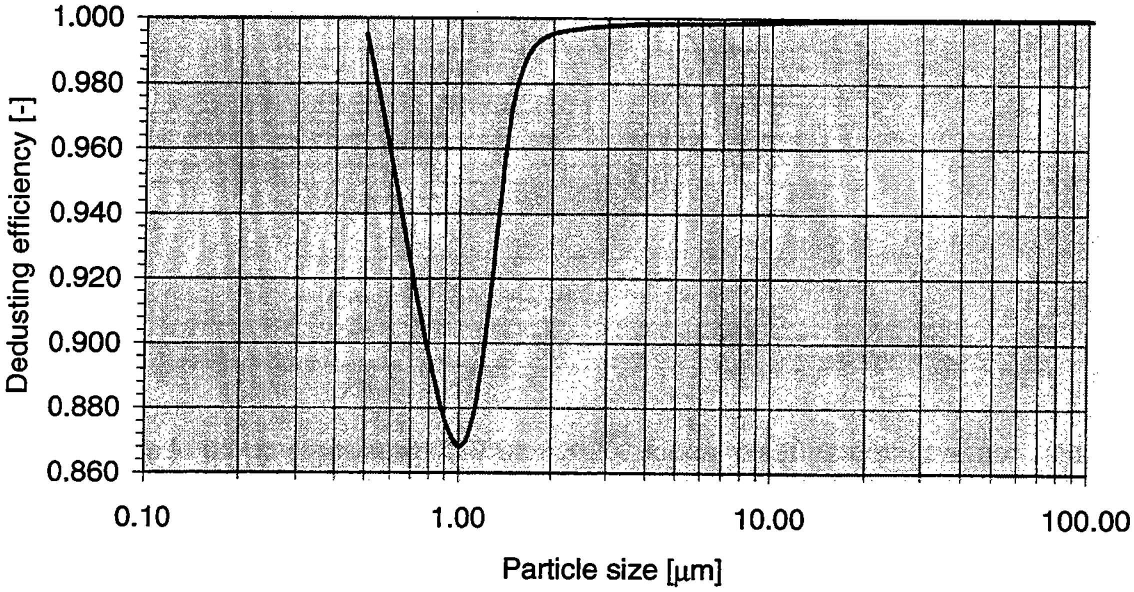
Figure 11 Dust removal efficiency as a function of the EP operating temperature



1.3.4.2 Size of Dust Particulates

According to Stoke's law for particles larger than 1 µm, the migration velocity is directly proportional to the particulates diameter.

Figure 12: Dedusting efficiency in function of the particle size



A dust with a mass mean diameter of 10 microns would require a precipitator only one-third the size of a system collecting dust with a mass mean diameter of two microns. As you can see, ϖ goes down when it is dealing with particulate in the 0.5 micron range and then starts to improve in efficiency when the particulate gets smaller (say 0.05 microns). That has to do with the two principals of particle charging which predominate in a precipitator. Field charging predominance for particulate greater than 1 micron in size and diffusion charging predominates for particulate less than 1 micron in size. That range around 1 micron is kind of a no-man's land where neither field charging nor diffusion charging has much effect. That is why the efficiency drops dramatically and then improves once the particles get even smaller.

What are other consequences for the EP operation based on the correlation between ϖ and particle size:

- EPs are classifying the incoming dust. The coarse particles are found in the first fields and the fine fraction in the last fields.

  This classifying of the dust can be used to extract selectively a dust portion enriched with condensibles like K_2O, SO_3 and heavy metals, thus avoiding generation of larger quantities of "contaminated" dust or enrichment of certain compounds in the process.

- Fine dust particulates and condensibles can be accumulated in the system and reduce the EP efficiency if they are not extracted from the last field.

- The particle diameter of the clean gas dust is generally below 10 µm.

1.3.4.3 Gas Temperature T

Gas and particulate temperature are usually the same because the particulates are suspended in the gas and the retention time of particulates in the gas is sufficient to reach a temperature equilibration.

The influence of the gas temperature T is mainly:

- Increased dust resistivity Ω at higher temperatures below 250°C (see para 1.3.4.2)
- Decreased dust resistivity Ω at higher temperatures above 250°C (see para 1.3.4.2)
- Increased actual gas flow Q at higher temperatures (see para 1.3.2)

1.3.4.4 Gas Humidity (dew point τ)

The water of the raw gas is originating from:

- Combustion ($4 C_mH_n + (4 m+n) O_2 \rightarrow 4 m CO_2 + 2n H_2O$)
- Water in ambient air
- Water in raw materials
- Water injection for gas conditioning

The dew point can be calculated as follows:

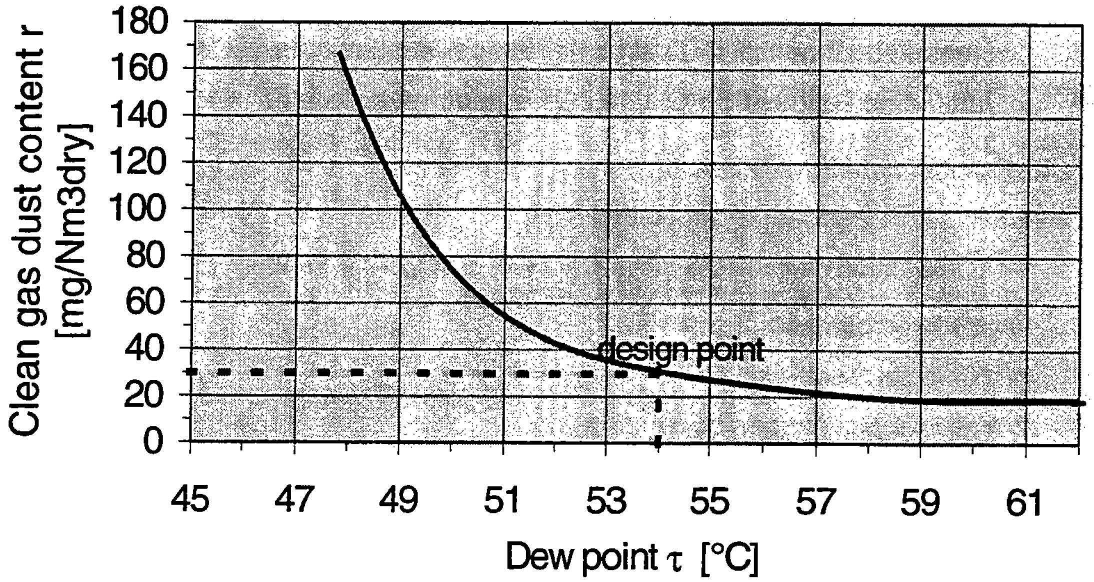
$$\tau=\frac{336.48}{5.3362-\sqrt{17.045+\ln(V_f \bullet P_{tot})}}-179 \qquad [°C] \qquad 7)$$

where:

V_f = Volume fraction of water vapour in the wet gas ($m^3\ H_2O\ /\ m^3_{wet\ gas}$)
P_{tot} = Total pressure (bar)

As described in para 1.3.4.1 the dew point is influencing the electrical resistivity of the dust particulates at temperatures below 250°C. This is responsible for the increased efficiency of the EP at higher dew points

Figure 13 **Example for clean gas dust content in function of the dew point τ at temperatures below 250°C**



The figure above shows the strong effect of gas dew point τ on EP efficiency η if no back ionization occurs. With back ionization the clean gas dust content r would increase even faster at lower dew points.

A typical example for the influence of the dew point are preheater kilns switching from compound operation (mill on) to direct operation (mill off). When the raw mill is in service, the moisture conditioning (11 % to 12 % at 110°C) of the gas is optimum. When the raw mill goes off line, the spray tower preceding both the raw mill and the EP cannot catch up quickly enough to increase the volume of water to make up for the moisture content lost when the raw mill goes down.

1.3.4.5 Gas Composition (not including water vapour)

The gas composition of clinker cooler vent air is fairly simple, however, the composition of kiln exhaust gas is a complicated cocktail of many different compounds.

Some compounds like SO_2 can enhance the EP operation by reducing the resistivity of the particulate surface.

Others like organic compounds or condensible alkalis reduce the EP efficiency. It is assumed that organic compounds attached to the particulate surface can increase their resistivity. Condensible alkalis can occur as very fine particulates $< 10\ \mu m$ significantly reducing the average migration velocity.

Condensibles like chlorides can increase the stickiness of the deposited dust on the electrodes which leads to thicker dust layers on the electrodes. This would increase the total electrical resistivity of the dust layer and therefore reduce the EP efficiency.

1.3.4.6 Gas Dust Load S, r and R

An increased raw gas dust load R has a positive effect on the migration velocity but cannot fully compensate the raise in the clean gas dust content according to equation 4.

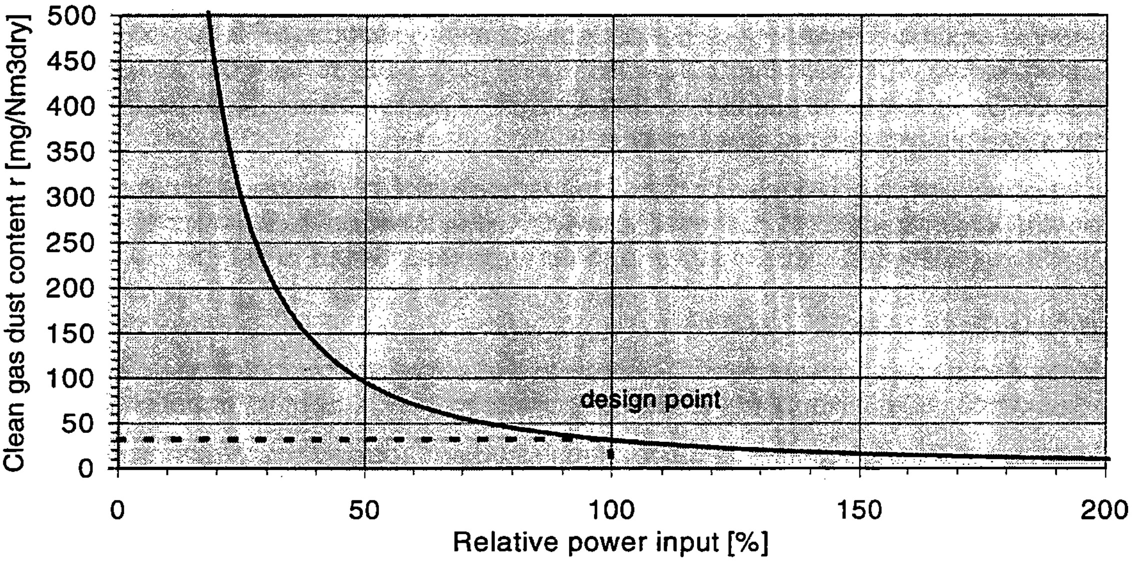
An increase of the clean gas dust content r is also increasing the migration velocity. According to the explanation under para 1.3.4.2 the lower the clean gas dust emission is the lower is the diameter of the dust particulates and smaller dust particulates have a slower migration velocity ϖ than larger ones.

Therefore, the required collecting area A is increasing exponentially with the reduced clean gas dust content r (see Fig. 6).

1.3.4.7 Energization of the EP

The collection efficiency of a precipitator is directly related to the total power for all fields on the precipitator. In general, the higher operating power levels that each field can achieve, the higher collection efficiency for that field.

Figure 14 **Example for clean gas dust content r in function of the relative power input**



Many people believe that a precipitator cannot work (achieve power levels) unless the gas is loaded with dust. This question can be easily examined by energizing any field of an EP in air. By that, it is meant that the kiln is not in operation, and that the temperatures have settled to ambient conditions. Furthermore, the precipitator is not bottled up and dampers are open, allowing for a natural stack draft through the precipitator. It is important to have some air movement in order to obtain a good "air load".

When a precipitator is energized in air, the following results could be obtained:

Table 1: **Example of energization of an electrical field of an EP under pure air (without dust)**

Precipitator Secondary Voltage (kV)	Precipitator Secondary Current (mA)
0	0
1	0
5	0
10	0
15	0
16.5	1
24	100
28	200
30.6	300
33.5	400
34	500
35.2	600
36.3	700
36.8	750

Actual results are dependent on T/R set size, type of high voltage electrode, and the electrical clearance between the electrodes.

The mA readings are synonymous with the actual current flowing in the precipitator. Current flowing in a circuit is equivalent to the number of electrons that are moving past the point in that circuit.

For current to flow in a precipitator, that means that electrons need to flow from the discharge electrode to the collecting electrodes in the precipitator. That means that the air in the precipitator must become a conductor. It is easy to think of the various conductors and realize that an insulator is a very poor conductor, a piece of copper wire is an excellent conductor, and an energized precipitator is somewhere in between. The air load demonstrates that current does not start to flow in a precipitator until (in this case) a voltage of 16.5 kV is achieved. That voltage is referred to as the corona onset voltage.

With moderate increases in voltage, a correspondingly increasing current results. If the alignment is correct between the electrodes in the precipitator, then the air load test should achieve either the primary or secondary current rating of the T/R set being energized. In the above example, we ran out of secondary current (705 mA) first.

Therefore, in order to get corona discharge in a precipitator, dust particles are not required. However, the concentration of particulate has a dramatic effect on the power levels in the precipitator. The term "space charge" is used to indicate a precipitator field that is collecting a significant number of fine particles or a heavy concentration of large particles. For our example, we will examine the latter, which is a common occurrence in cement plant precipitator applications.

Space charge - high dust concentrations

As we saw in the section on air load, since there are no particles (dust) in the inter electrode space, there can be no space charge. However, with the influence of a large concentration of large particles, see what affect it has on these two wet process cement kilns. Kiln No. 1 has a cyclone mechanical collector in series with the precipitator, whereas kiln No. 2 does not. The automatic voltage controls for those two precipitators were found to be operating as follows:

Table 2: Energization of two EPs with different dust loads Kiln No. 1: low dust load, kiln No. 2: high dust load

Unit	Amps	Volts	mA	kV	kW	Sparks/Minute
Kiln No. 1-1	123	337	664	50.1	27	0
Kiln No. 1-2	142	247	758	36.2	23	0
Kiln No. 2-1	9	232	39	57.5	1a	20
Kiln No. 2-2	16	324	71	52.0	2	14
Kiln No. 2-3	115	465	940	48.0	38	3
Kiln No. 2-4	120	346	924	35.1	28	0

Because kiln No. 2 does not have the mechanical collector preceding it, the dust loading (concentration) is significantly higher than kiln No. 1. The voltage control readings show the affect of space charge. Space charge is indicated by high voltages, but more importantly, by extremely low current. It is the absence of current flow that can be of significance.

When asked what is the more important parameter, precipitator voltage (kV) or precipitator current (mA), often times people will say kV. They are partially correct in most cases, but not in this case. Precipitator voltage is responsible for pushing the dust particles toward the plates. Current is responsible for keeping them there. So although kiln No. 2, field 1 has a lot of pushing forced, (57.5), it has no holding force. Most of the dust re-entrains onto the next field.

The other important point to note is that sparking in a precipitator (an electrical breakdown of the gas) is directly related to the precipitator voltage levels. That is why inlet fields have sparking (because of the high kV) whereas outlet fields sometimes do not.

If one looks at the flow of current from the transformer / rectifier to set to the high voltage electrodes through the dust laden gas, to the collecting plate and back to the T/R set (through earth ground) as shown in Fig. 15 the effect of the ion mobility may become apparent.

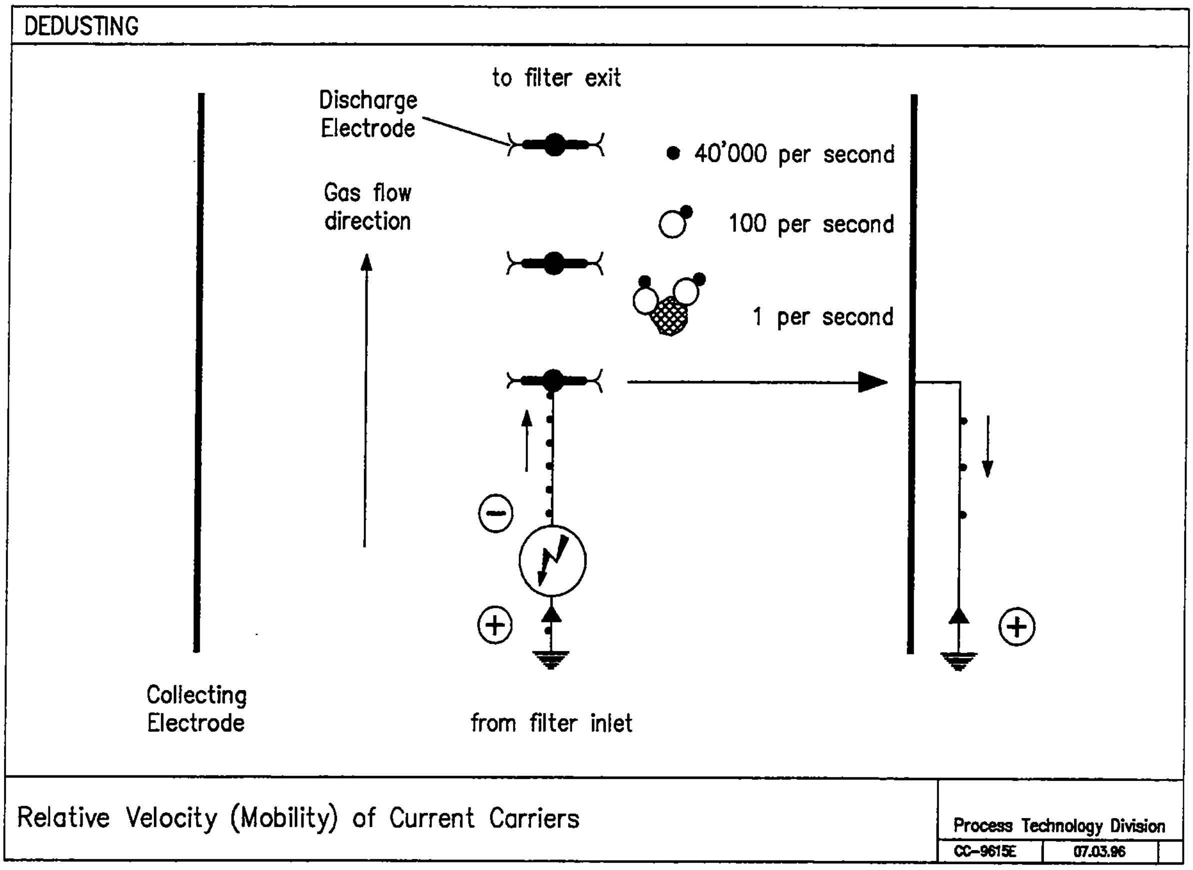
The air load demonstrated that in air without dust, the main current carriers are the free electrons and the negative ions. These two characters can be compared to running backs on a football team. They are very swift moving and seek the holes, and the mA meter counts a lot of them during an air load.

With the introduction of dust into the precipitator, the ion mobility changes dramatically. The charged particles, which move very slowly, establish a "particulate space charge" in the inter electrode space. Fig. 15 gives an idea of their relative velocity.

The affects of high space charge can be both influential and detrimental. On the positive side, high voltages created by space charge in turn create higher "electric fields". The electric field is the pushing force against the dust particles, accelerating them towards the collecting plates. Higher accelerations toward the collecting plates can result in increased efficiencies.

However, as in our example in table 2, kiln No. 2 was operating with very low current levels. Therefore, the space charge enhanced the particulate collecting field (high voltages), but also contributed towards a suppression of the corona current. Corona current directly affects particle charging. The higher the particle charging ensure that the dust loss due to particle re-entrainment is diminished. If the corona is suppressed, this can promote re-entrainment. That is the case on kiln No. 2.

Figure 15 Relative velocity (mobility) of current carriers



The peak value of the precipitator voltage is limited by the dielectric constant of the gas. The arc-over voltage is the only value which determines the maximum possible precipitator voltage. The total power input and therefore the EP efficiency η are strongly influenced by the applied voltage.

$$P_c = I_m \cdot \frac{U_p + U_v}{2} \qquad 8)$$

where

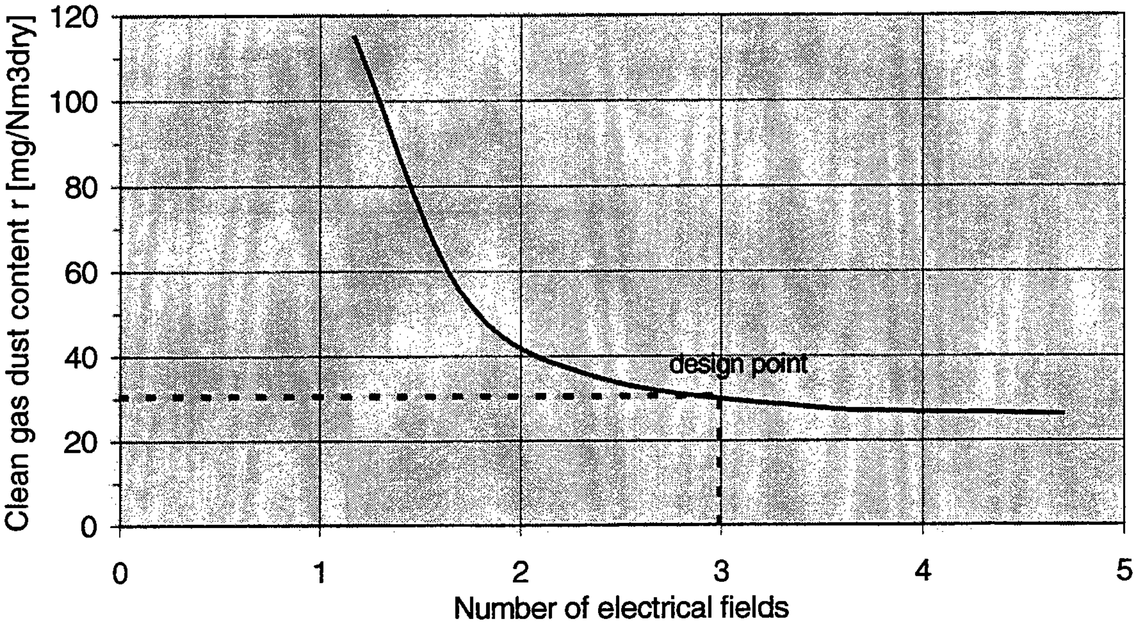
I_m = Mean secondary current
U_p = Secondary peak voltage
U_v = Average secondary voltage

The factors determining the maximum possible precipitator voltage can change quickly. Therefore, the efficiency of the automatic voltage control, that is adjusting the voltage to operate at the maximum value, is directly correlated with the EP efficiency.

The functioning of HT-rectifiers and automatic voltage control is explained in para 1.4.

The electrical operating behaviour is also changing over the length of the field. Gas turbulence and distribution, dust content and particulate size at the EP inlet are very different from the ones at the EP exit. Therefore, to optimize the energization of the EP the electrodes should be subdivided mechanically and electrically in the length direction.

Figure 16 **Clean gas dust content r in function of the number of independent electrical fields at constant collecting area A**



1.3.4.8 EP Design

The equipment parts with the main influence on the migration velocity are:

- Gas distribution screens
- Electrode
- Electrode cleaning systems

Gas distribution

In general terms the ducting leading to the precipitator and the inlet and outlet funnels should be designed to ensure a proper gas velocity distribution in view of utilizing the whole collecting area and avoiding negative velocity effects. From a practical viewpoint this implies different requirements to the gas distribution in the different parts of the precipitator, and too strictly formulated numerical rules for deviation from uniformity may not be justified.

The inlet gas distribution must be sufficiently uniform to secure a reasonable uniform current distribution. This is especially important for precipitators for processes with high resistivity dust and fine particles. A rule of thumb says that the standard deviation of the gas velocities in the EP should be below 30%.

The velocity profile at the outlet should be specifically selected to reduce the risk of re-entrainment in the bottom region.

Sneakage of dust laden gases around the electrically energized electrode system must be kept at an absolute minimum, in particular at the bottom part of the precipitator. And large eddies in the bottom hoppers caused by the velocity "slip" at the bottom of the electrode system may aggravate the influence from sneakage because particles already picked up by the hopper are swept into the main flow again.

High local velocities may scour away already precipitated dust from the collecting plates. In this case a good gas distribution combined with high average velocity may not be superior to a bad gas distribution combined with low average velocity.

The gas distribution may influence the dust space charge distribution and thereby the current distribution in a separately energized precipitator field. In areas with low velocities or, in extreme situations, areas with recirculating flow, the particle concentration will be much lower than in corresponding areas with higher velocities. Consequently the power input will be limited in the high velocity areas causing a reduction in overall efficiency. In particular with high resistivity dust such uneven current distribution will cause back ionization and frequent sparking, resulting in lower average voltage and current and increased dust re-entrainment. Due to the turbulence the gas distribution in each separate duct will tend to improve through the precipitator, thus smoothing the dust space charge. However, a skew cross distribution at the field inlet will not be smoothed to the same extent, and so the horizontal gas distribution should be fairly uniform in order to maintain a proper current distribution.

Finally, high local gas velocity, combined with high dust content, can result in erosion of the edges of the collecting plates and other internal parts of the EP. Low gas velocity can cause dust build ups.

The cross section of an ideal EP should be designed to achieve an average gas velocity of

Kilns	0.8 - 1.0 m/s
Clinker coolers	0.7 - 0.9 m/s

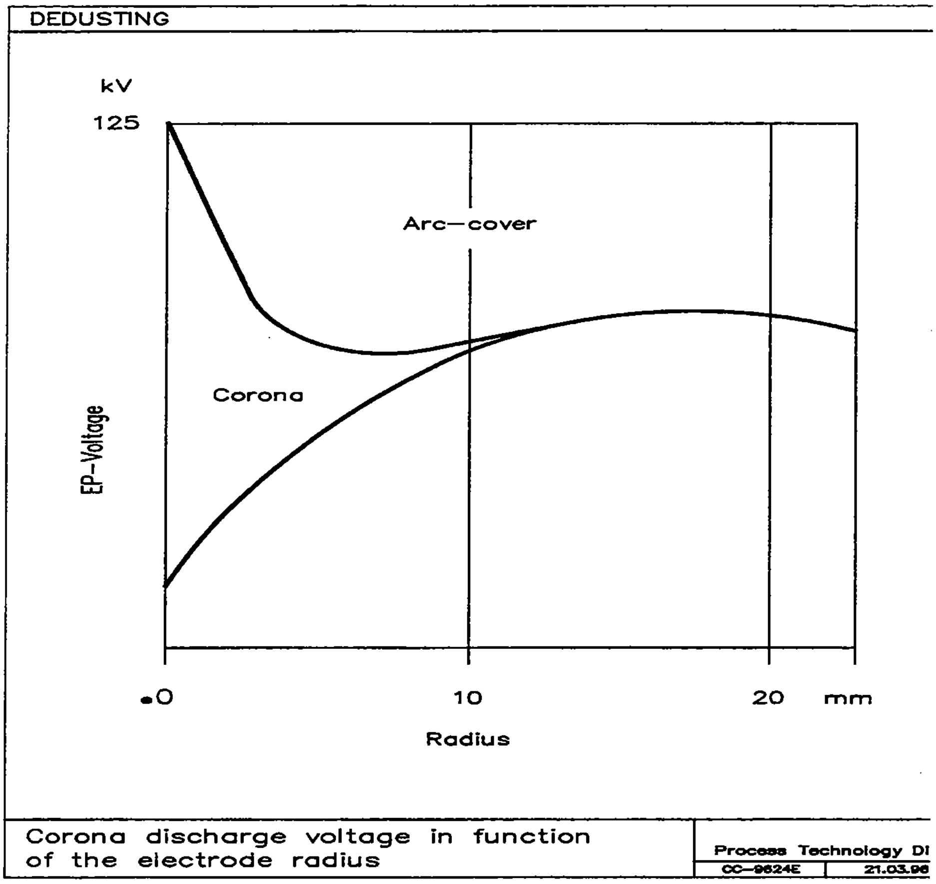
The gas velocity should not drop below 0.5 m/s to maintain a suitable gas distribution.

Electrode design

The electrodes have two duties. First emission of electrons (discharge electrode) and second the collection of the dust (collecting plate).

The energization of the fields or in other words the supply with voltage and current is influenced by the discharge electrode design. Various electrode designs to achieve optimum voltage or / and current are employed by the suppliers. An important factor is the corona onset voltage which depends mainly on the radius of the electrode (plan strips) or the radius of spike peaks. The corona onset voltage is increasing with the above mentioned radius.

Figure 17 Corona discharge voltage in function of the discharge electrode radius



In applications, where a high current is required (high dust load, low resistivity), the electrode radius should be small. In situations, where current must be reduced and voltage increased (high resistivity dust -> back corona) electrodes with larger radius (without peaks) can improve the efficiency.

Since corona discharge is also greatly affected by dust settling, the discharge electrodes need rapping, which means that their oscillation behaviour is of utmost importance. Best results have been obtained with rigid frame-mounted electrodes or rigid electrodes.

For maximum collection efficiency, the collecting plates must be rigid to maintain the critical spacing between the different electrodes and withstand bowing during operation. At the same time, they must facilitate the efficient transfer of rapping energy for effective cleaning. Not optimum cleaning can amplitude back corona effects and generally reduce the EP efficiency.

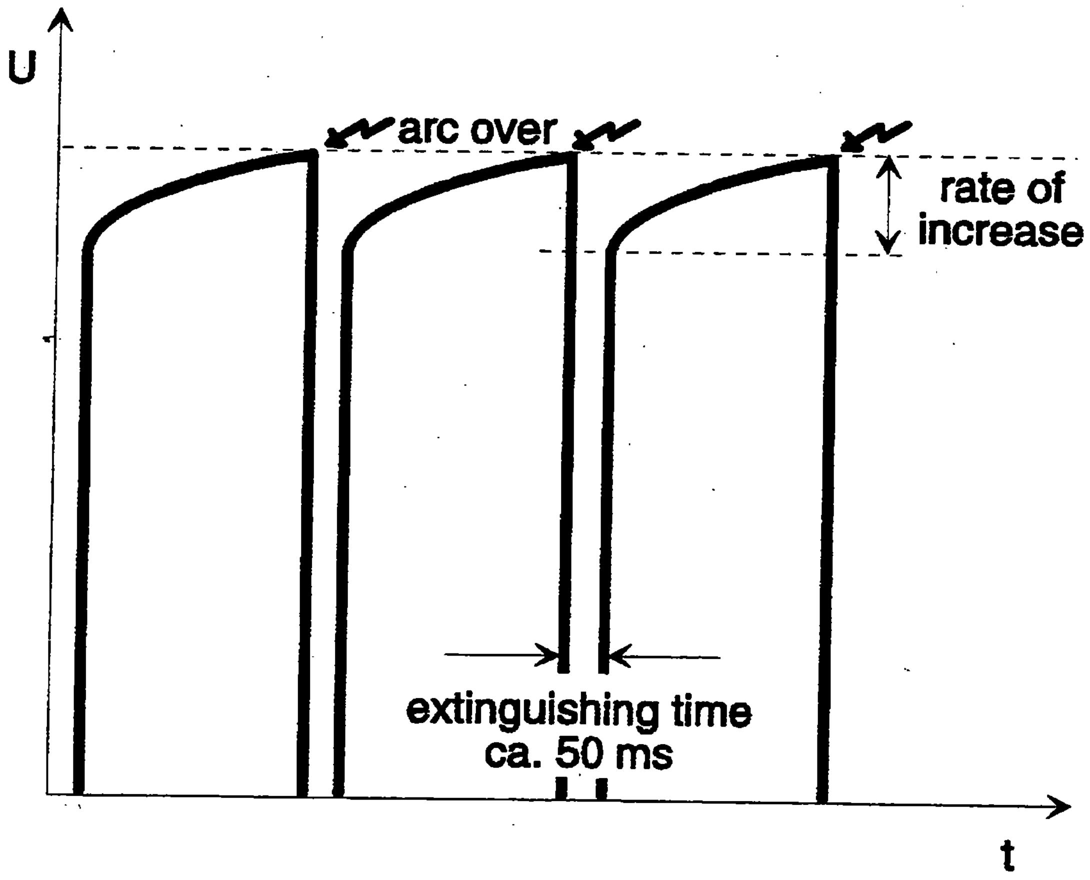
1.4 HT-Rectifier

The High Voltage Rectifiers are responsible for optimum energization of the EP under different operating conditions. Optimum energization means:

- Clean gas dust content r below the target
- Minimum energy consumption

The precipitator energization has a very strong influence on precipitator collection efficiency. As a result of this recognition, the microprocessor-based controller for precipitator high voltage power supplies have in recent years become the general standard. These programmable, fast reacting, digital controllers can implement sophisticated control strategies through their monitoring of secondary current and voltages, including differentiation of reactions according to type of arc or spark in the precipitator, arc quenching, fast voltage recovery after arcing without reignition of the arc, automatic current limitation to the nominal current at overload or short circuit conditions and operation at a precipitator current level just below the onset of "back corona". They continuously control flash-over rate and power input to the precipitator for optimum performance.

Figure 18 **Automatic voltage adjustment. Behavior of EP voltage at constant arc-over limit**



Most microprocessor-based transformer / rectifier controllers have or can easily be supplemented with an option for semi-pulse energization, as described in the following:

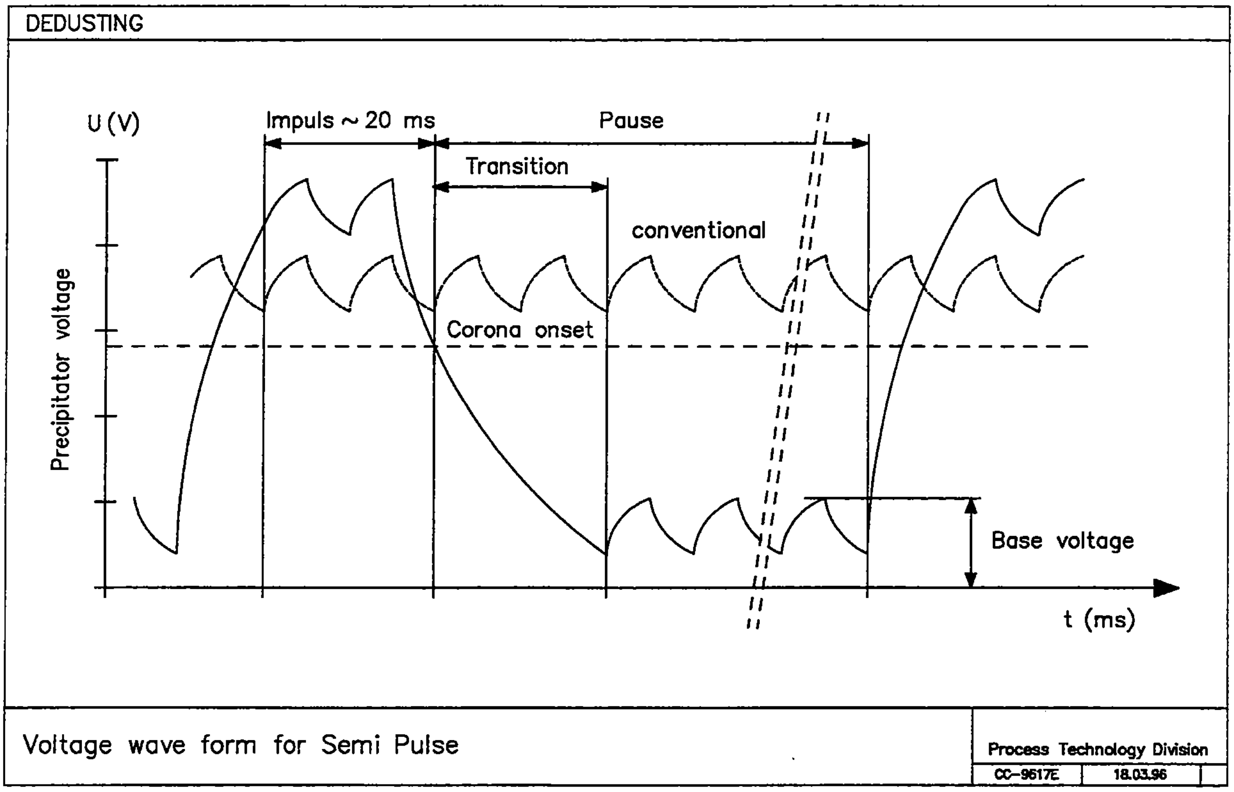
1.4.1 Semi-Pulse Energization

An inexpensive method for reduction of precipitator power consumption, and in some instances also improvement of precipitator performance, is also known under various trade names such as semi-pulse intermittent energization and energy-control.

Semi-pulse energization is implemented at a conventional thyristor controlled full wave transformer / rectifier simply by suppressing for instance two out of three, or four out of five half waves. The ripple of the precipitator voltage hereby becomes more pronounced than with conventional energization, resulting in a voltage wave form that resembles a DC base voltage superimposed with long duration pulses.

The intermittent nature of the corona discharges gives this form of energization certain properties resembling those of the later discussed pulse energization. Semi-pulse has, in some cases, been able to improve the performance of precipitators operating with medium to high resistivity dust, but as a rule not to the same degree as pulse energization. Its main advantage is the resulting power savings. Power saving up to 90% and emission reduction of up to 50% were reported.

Figure 19 Voltage wave form for semi-pulse energization



1.4.2 Pulse Energization

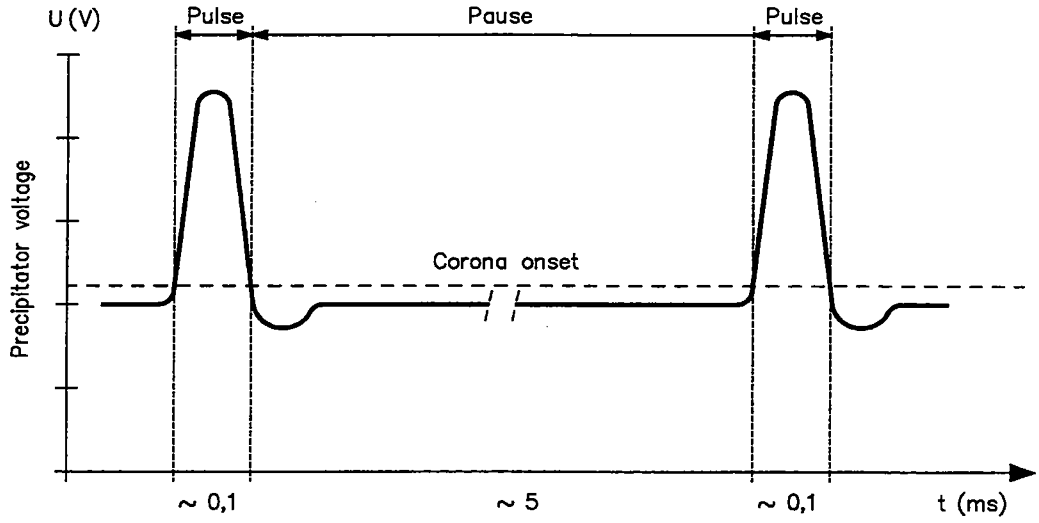
Advances in high-power switching technology in recent years have made it possible to develop pulse energization systems with sufficient reliability and capacity to energize large precipitators.

With pulse energization short duration, high voltage pulses are repetitively superimposed on a DC base voltage. Some energy conserving pulse energization systems utilize pulses with a duration in the order of 100 microseconds and pulse repetition frequencies up to 200 pulses per second.

Pulse energization makes it possible to attain more favorable electrical conditions for high resistivity dust than is obtainable with conventional DC energization. Pulse energization, therefore, can successfully be used to improve the performance of an existing precipitator operating with high resistivity dust or to reduce the size of a new precipitator installation for a high resistivity application, as for instance with the so-called "hot" precipitators for kilns. Power saving of up to 90% and emission reduction of up to 60% were reported.

Figure 20 Voltage wave form for pulse energization

DEDUSTING



Voltage wave form for Pulse Energization

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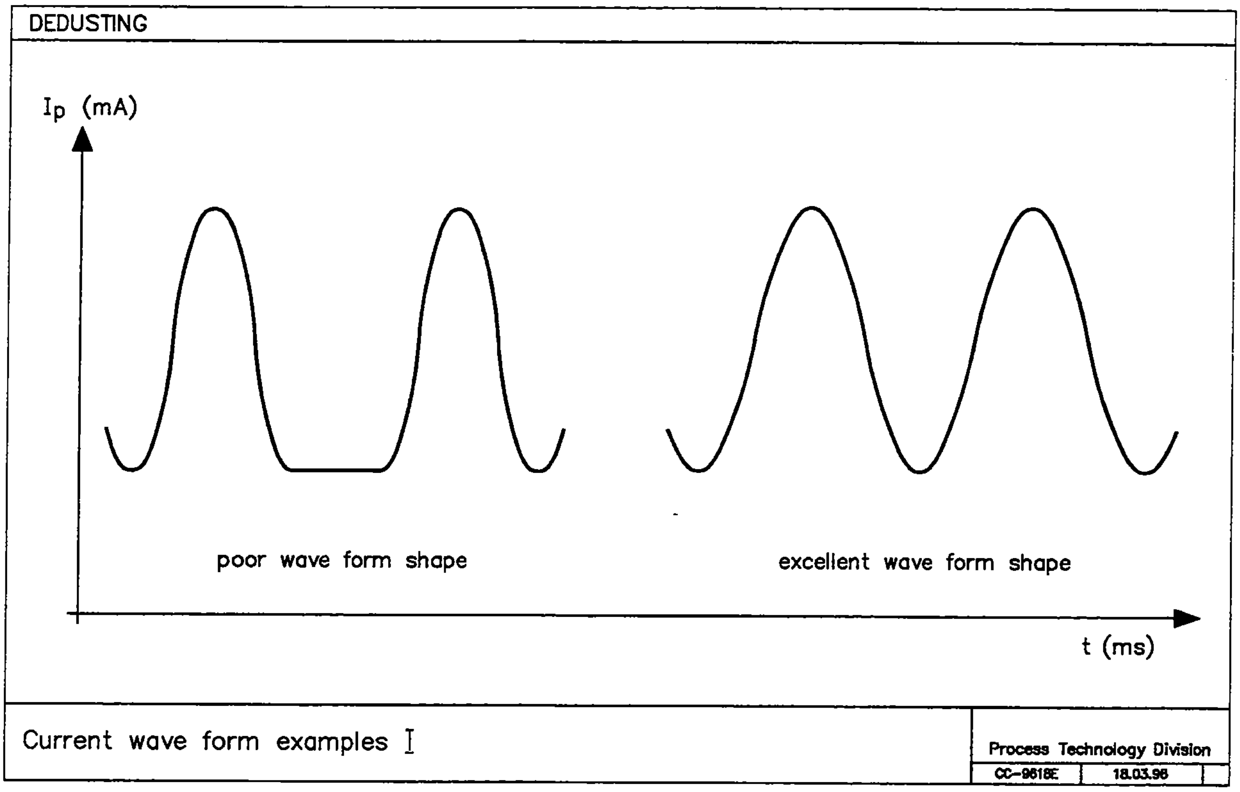
CC-9616E | 18.03.96

1.4.3 Improvement of Voltage and Current Wave Form Shape

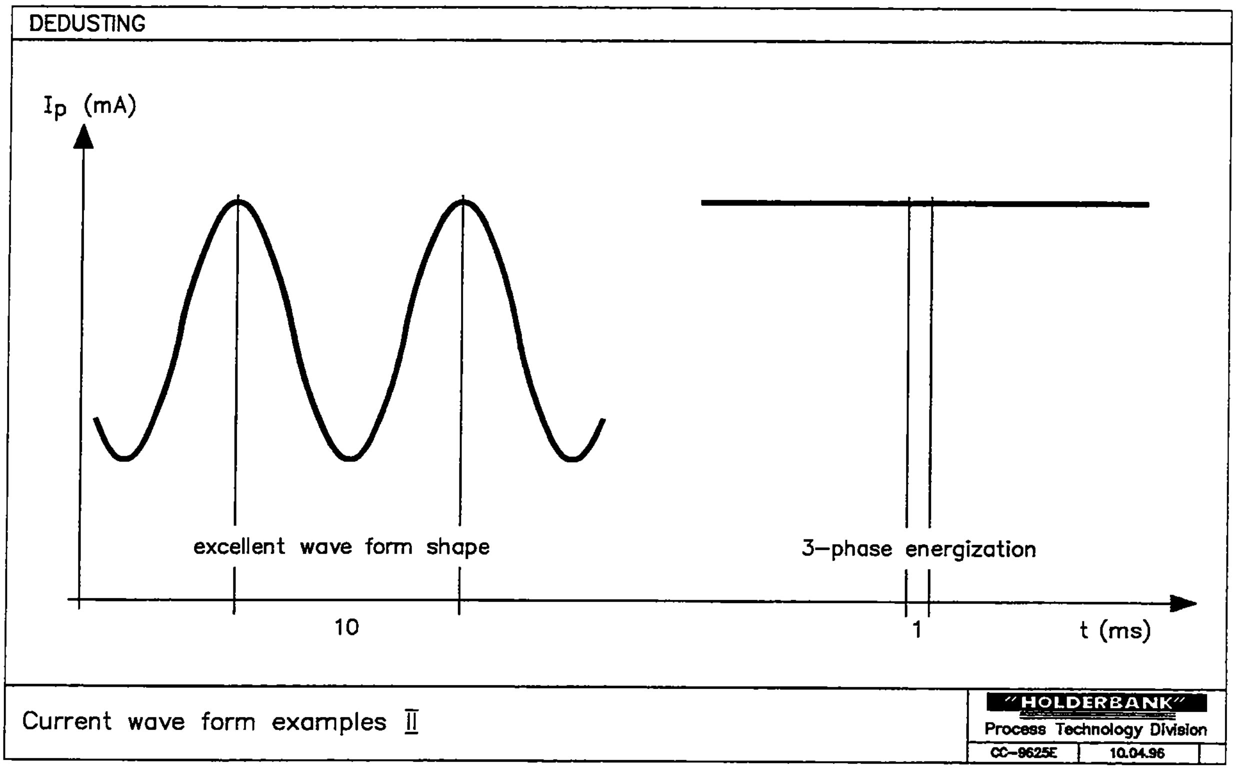
Modern precipitator power supplies include silicon controlled rectifiers (SCR's) and current limiting reactors (CLR's). SCR's and CLR's are designed to produce an optimum energization of the EP at one specified process condition. Since it is known that this condition can change very frequently, the current and voltage input have to be adjusted continuously. Operation of CLR's at conditions which are not according to the design specifications can produce a poor current wave form shape (poor form factor) which leads to a reduced power input. This can be corrected with a variable inductance current limiting reactor (VI-CLR).

Figure 21 Improving wave form shape with variable inductance current limiting reactor



Another more expensive way to increase the power input is the utilization of a 3-phase energization. The transformer is operated with a square wave voltage with a frequency of 500 Hz. This produces a very flat direct voltage that can under certain circumstances result in a higher power input. Unfortunately, very little experience is available for this system.

Figure 22 Improving current wafe form shape with 3-phase energization



Intelligent EP control systems do limit the power input if additional power input does not result in significantly reduced dust emission (see Fig. 14).

1.5 Voltage-Current Curves

A voltage-current curve to a precipitator troubleshooter is like a stethoscope to a cardiologist. When a precipitator is running, we cannot see what is happening inside that might affect its performance. However, by a close examination of the relationship between the voltage and current levels in the operating precipitator, one can predict what is affecting performance.

A V-I curve is run by taking the voltage controls to zero then slowly increasing the power levels, recording both the kilovolts and milliamps at convenient intervals (usually 50 mA or 100 mA) until the voltage control sparks over. A curve can then be drawn from the points collected utilizing the "X" axis for the kilovolts and the "Y" axis for the milliamps. Some typical V-I curves for a dry process cement kiln are shown on Fig. 23. Note that the voltage and current corresponding to each field reflects the voltage and current relationships as first shown in Table 2 of our precipitator example.

When there are problems with the operation of the precipitator, Fig. 24, would be more helpful for troubleshooting. For example, the high resistivity dust as indicated by low current levels in the outlet fields may show up as the "moderately high" dust resistivity curve shown on Fig. 24. This short, stubby curve shows corona onset voltage as normal (say around 18 kV), but current level only increases to a very low level as opposed to the way an outlet field should, as shown on Fig. 23.

This contrasts with a misalignment of the electrodes (wire-to-plate spacing) in the precipitator. Misalignment exhibits itself by a very low corona onset voltage (the electrical clearance is decreased), and the spark over.

These curves can also be utilized to show if there is excessive dust buildup on the high voltage electrodes. Excessive dust buildup exhibits itself almost as if the wire diameter of the high voltage electrode has been increased. Dust buildup on the wire has the same effect of increasing the corona onset voltage from the normal range of 15 - 20 kV on up to 25 to 35 kV. The problem with wire buildup is that you are not able to achieve as high a current as if the wires were clean. Remember, a precipitator needs both high voltage and high current levels.

Figure 23 Normal precipitator voltage - current (V-I) curves

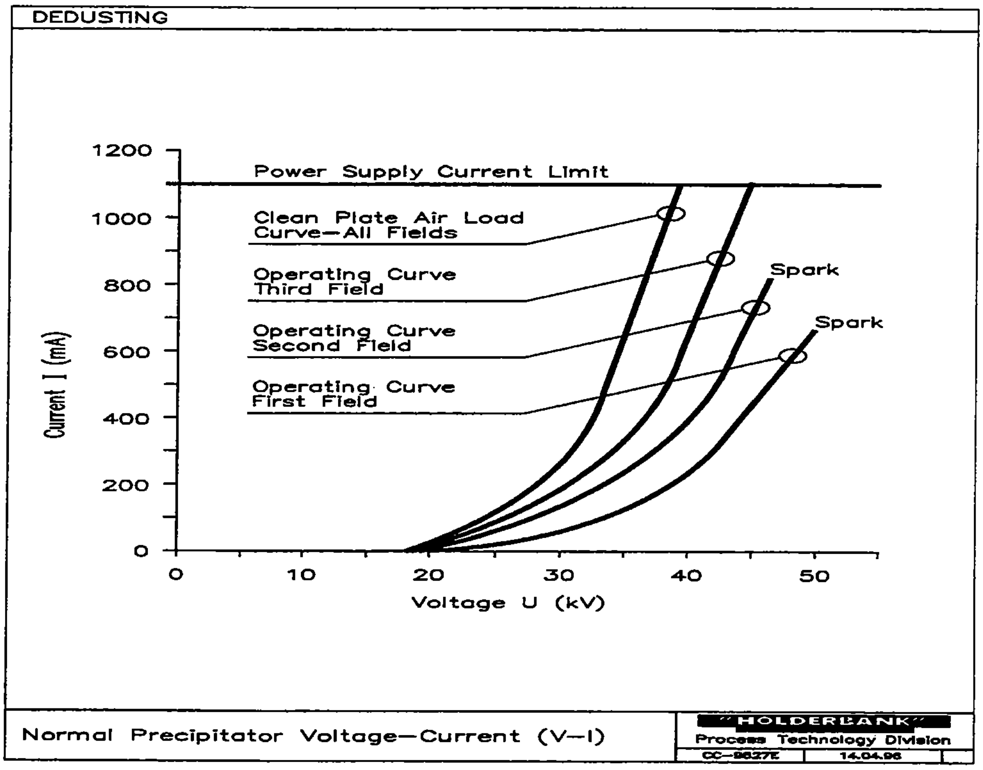


Figure 24 Abnormal precipitator current-voltage curves

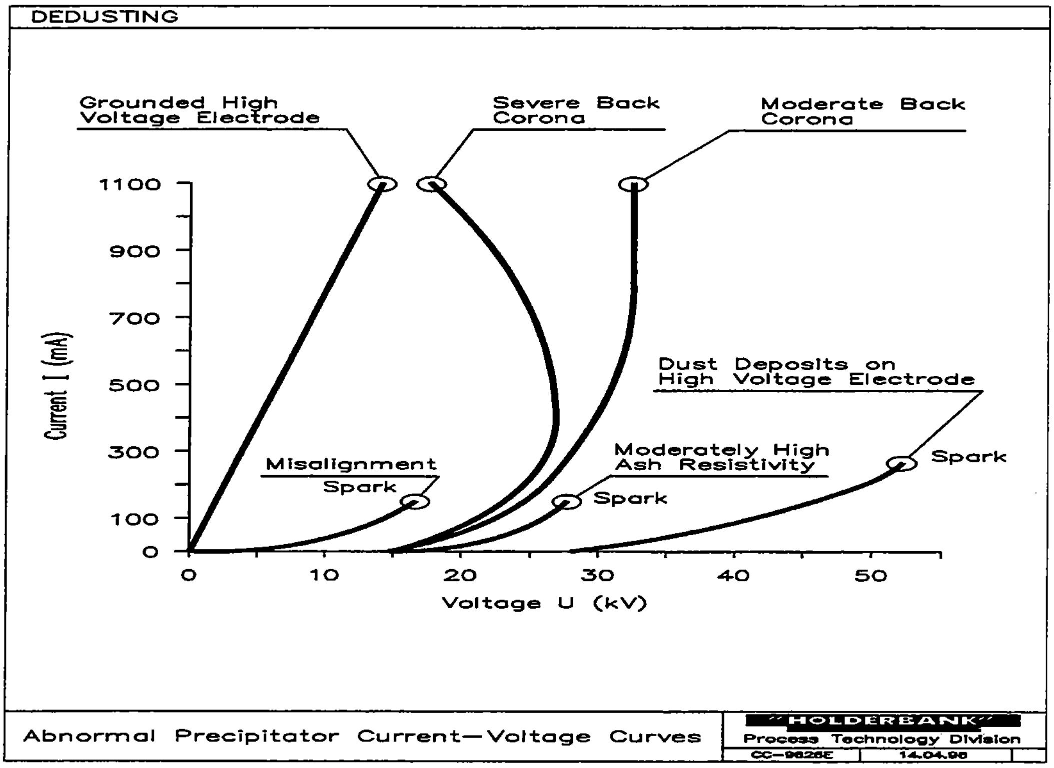


Table 3: Influence of some variables on EP's dedusting efficiency

Variables	Variation	Efficiency	Dust Emission
Raw gas dust content R	↗	↗	↗
Gas flow Q	↗	↘	↗
Collecting area A	↗	↗	↘
Electrical resistivity of the dust Ω	↗	↘/↗	↗/↘
Temperature T1 (<200°C)	↗	↘	↗
Temperature T2 (>300°C	↗	↗	↘
Particle size ∅ (> 1 µm)	↗	↗	↘
Humidity (τ)	↗	↗	↘
Organic emission c	↗	↘	↗
Power input P	↗	↗	↘
Standard deviation of gas distribution	↗	↘	↗
Misalignment of electrodes	↗	↘	↗
Speed of the controller for EP energization	↗	↗	↘

Figure 25 Longitudinal Section of a 2-Field EP (Lurgi)

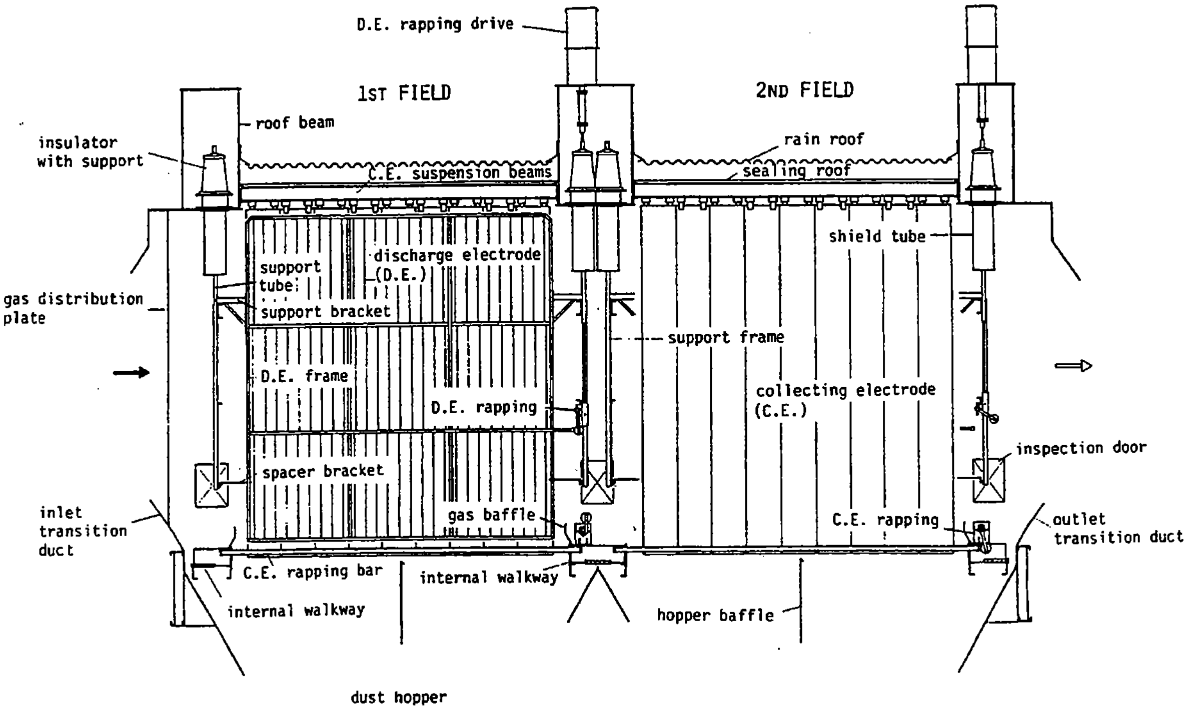


Figure 26 3D view on a 2-Field EP (ELEX)

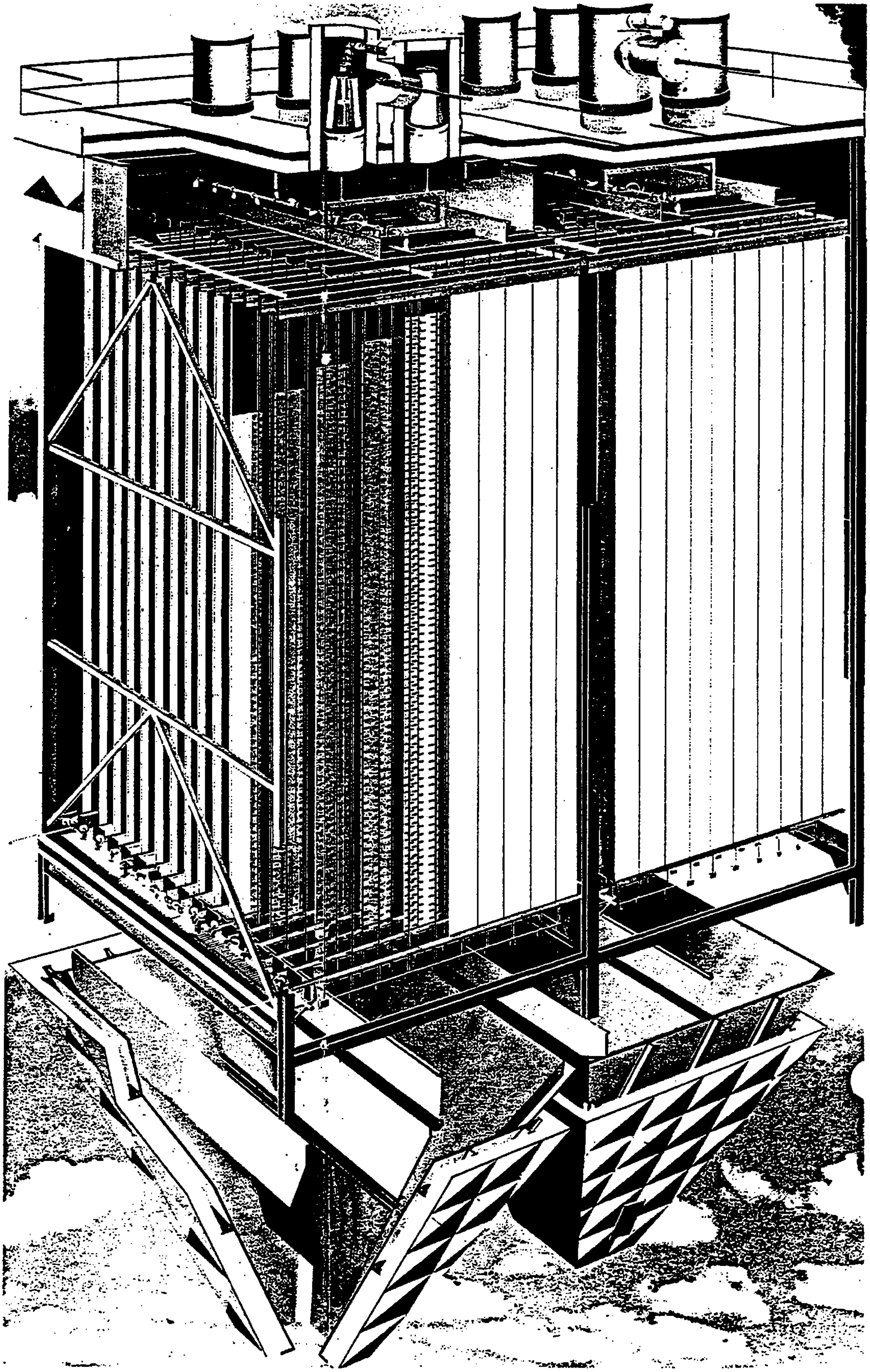


Figure 27 Insulator Chamber FLS (Type C)

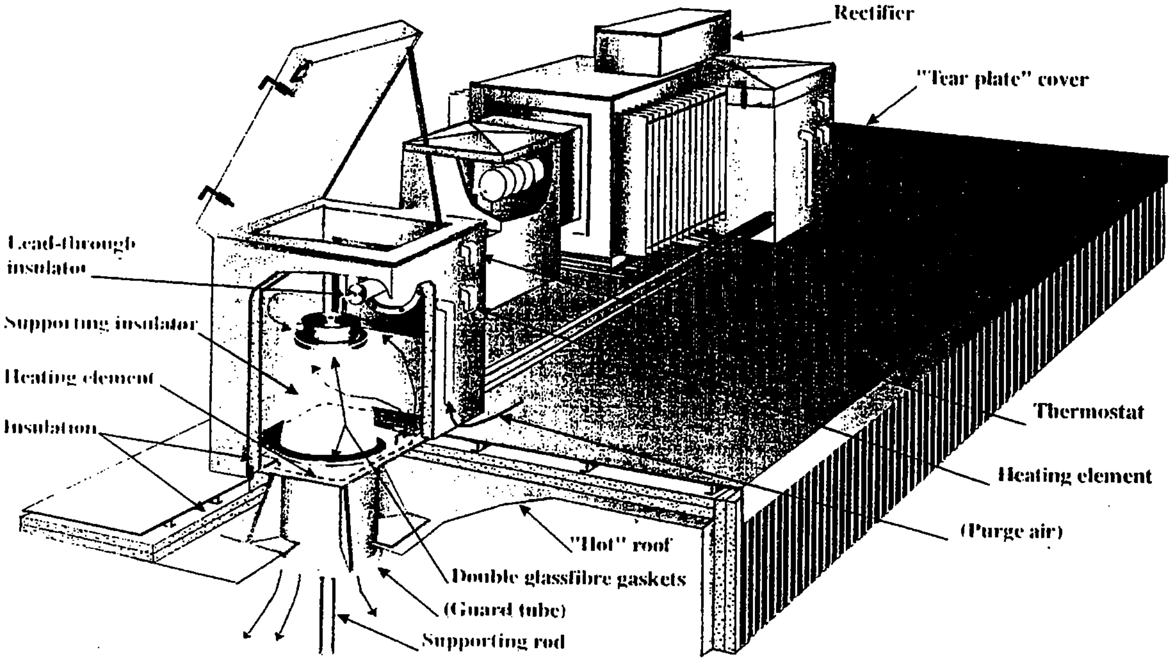


Figure 28 Electrode System (Lurgi)

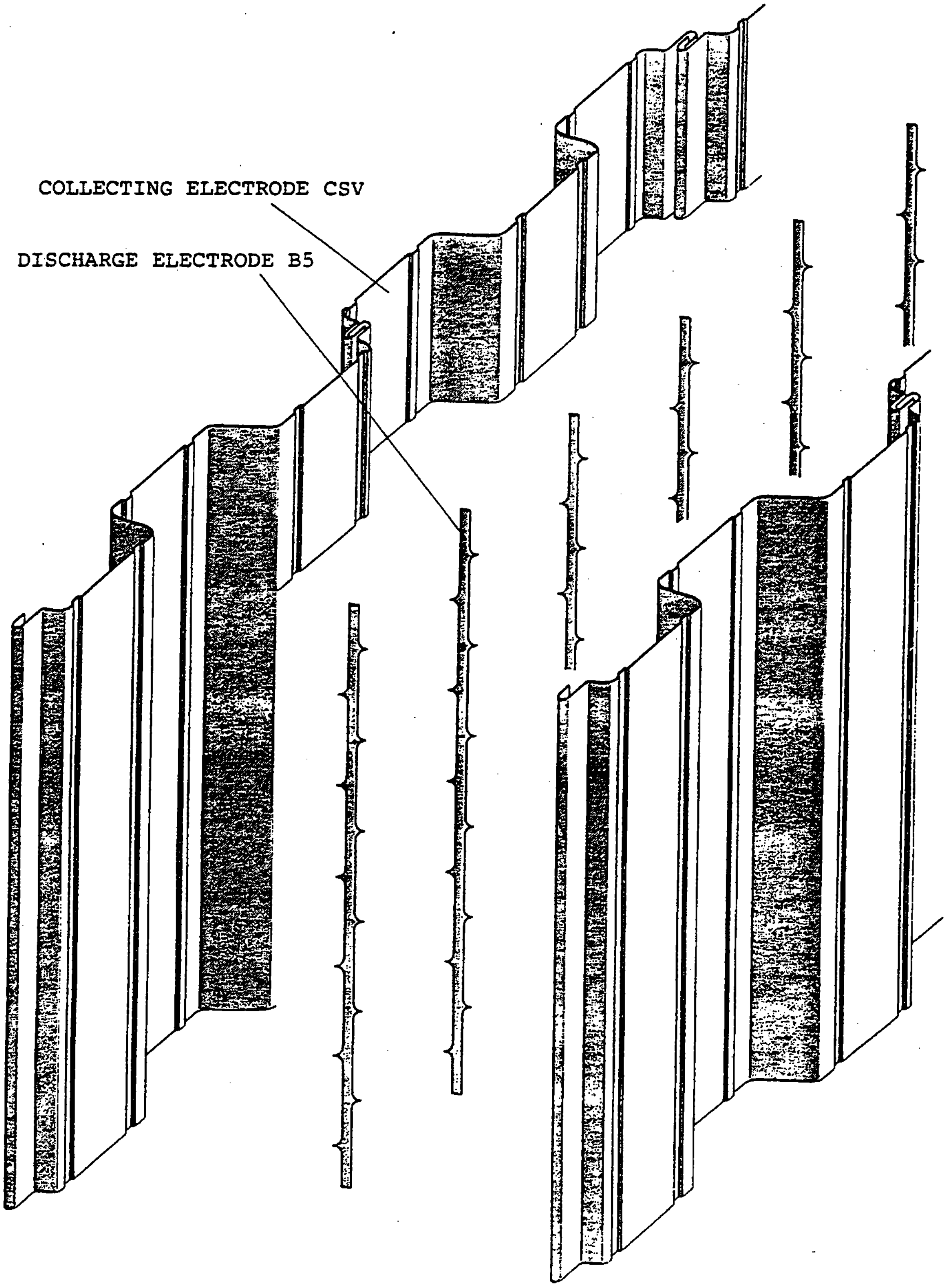


Figure 29 Collecting Electrode Rapping System (Lurgi)

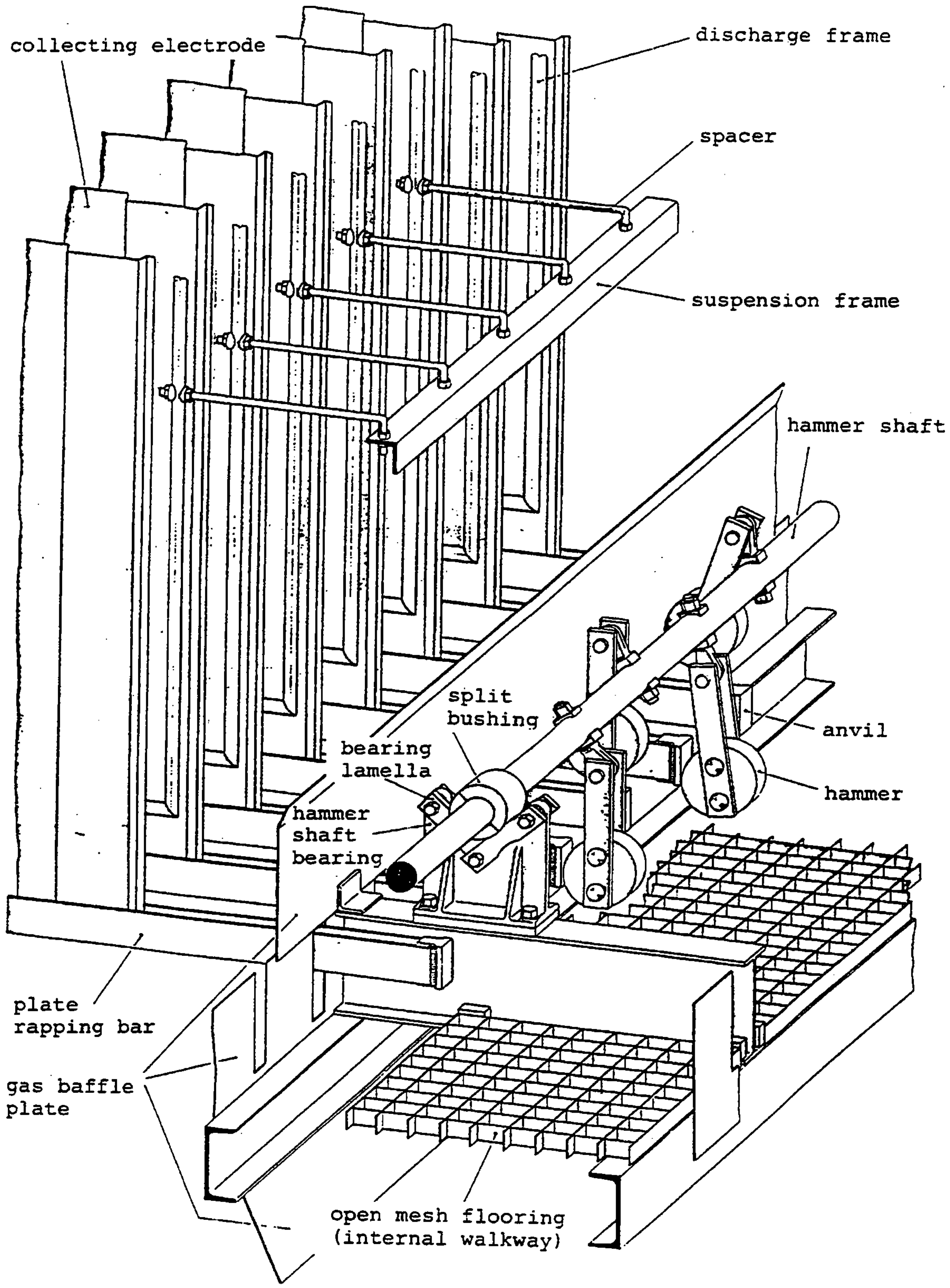


Figure 30 Suspension and Rapping of Discharge System (Lurgi)

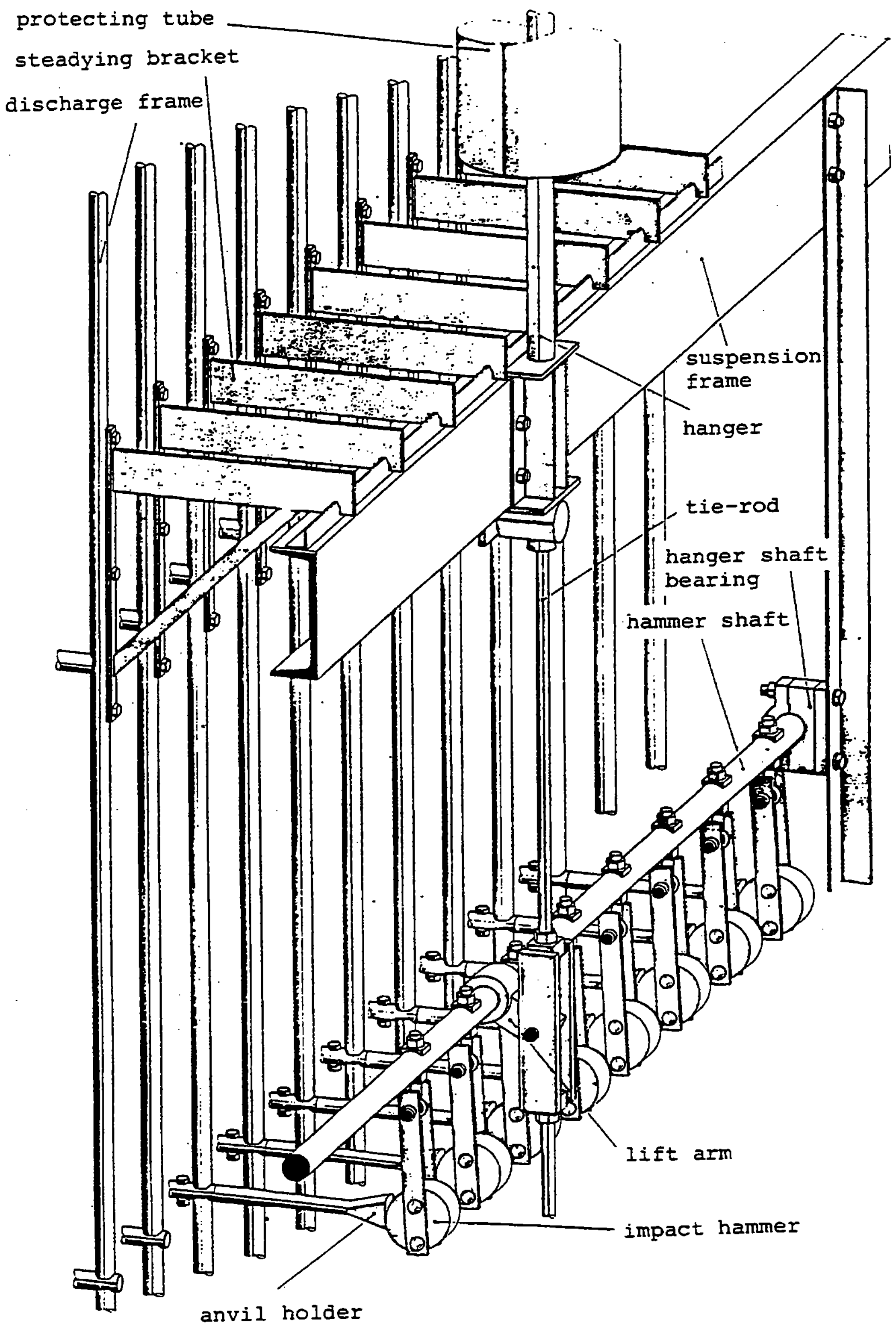


Figure 31 **Gas Distribution Screen (FLS)**

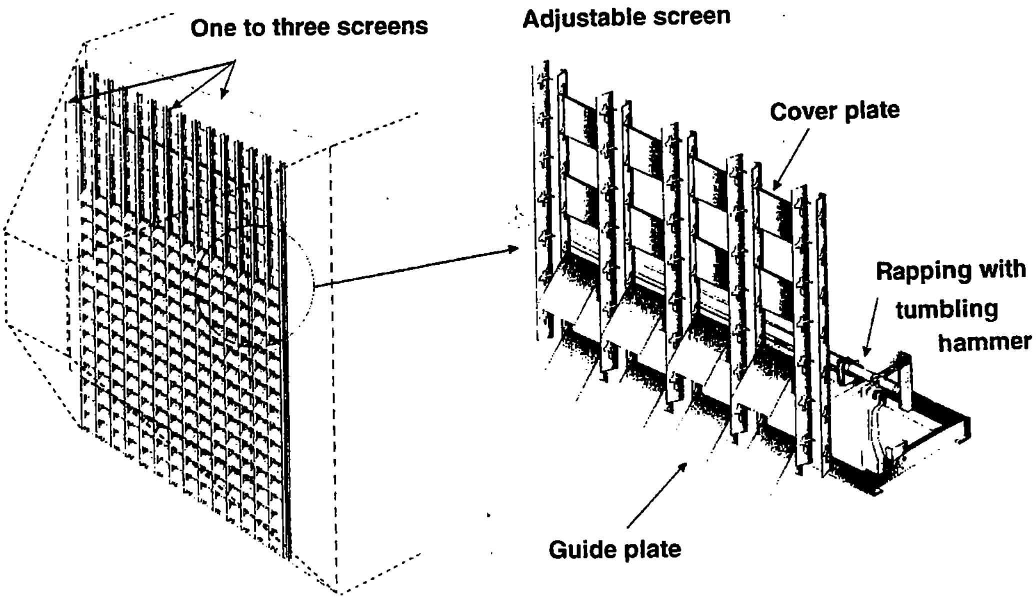


Figure 32 **Dust Removal System (FLS)**